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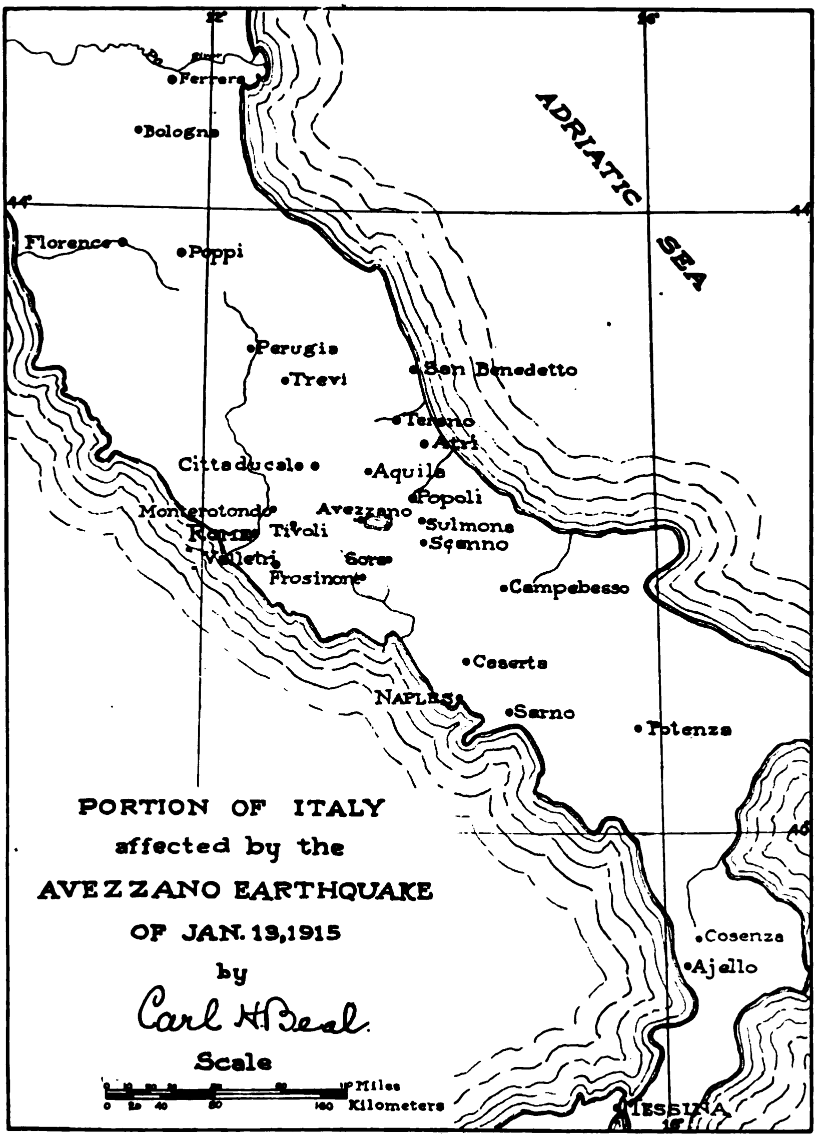

Italian Earthquake, January 13, 1915.

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The Bulletin of the
Seismological Society of America

VOL. V MARCH 1915 NO. 1

THE AVEZZANO EARTHQUAKE OF JANUARY 13, 1915

By Carl H. Beal

On the morning of January 13, 1915, at 6:53 (mean Greenwich time), the central part of Italy was disturbed by one of the most destructive earthquakes on record. Up to the present time very few scientific details have become available, and the following notes have been taken, therefore, from newspaper reports and from a brief article by Mr. C. Davidson published in *Nature* of January 21, 1915, vol. 94, p. 565.

The district which was most seriously affected is about sixty miles east of Rome, in the thickly settled mountainous country dotted with the cities and villages of the middle ages. The city of Avezzano, which was completely destroyed, lies in the province of Abruzzi on the edge of Lago Fucino in the Appennine mountains, at an elevation of over 2,000 feet. Lago Fucino is the marshy bed of a large dried up lake, which was probably caused by a change in river courses due to faulting in the vicinity of Avezzano. The alluvial plain of this old lake bed is about ten miles across, and the cities of Avezzano, Ortucchio, Gioja de Marsi, Pescina, Cenchio, Celano, Paterno, and Luco, all of which suffered most severely from the earthquake, lie around its border.

The geology of this portion of Italy is made up entirely of several sedimentary terranes which range in age from Jurassic to Quaternary, the volcanic activity, so common in Italy, being confined entirely to the west coast. The higher mountain ranges near Avezzano rise to an altitude of from 6,000 to 7,000 feet and trend generally northwest and southeast, the direction apparently being determined by a series of nearly parallel fractures which extends from a region southeast of Avezzano northwest to the vicinity of Cittaducale, where it is joined by another series of fractures which strikes north and south across the Sabine mountains. A fault is known to pass through Luco, Cappelle, Sourcola, and very close to Avezzano, and as these cities were completely demolished, it is quite probable that movement along this fracture caused the shock. This belief is strengthened by the fact that the ground near Ortucchio is said to have been cracked, and a mountain near Luco, about eight miles southeast of Avezzano, was split.

Modern improvements have made but little impression on these generally unknown provinces, and the loss of so many lives by the earthquake of January 13th may be directly attributed to the poorly constructed buildings, which were erected before reinforced concrete was known. Davidson states that "there can be little doubt that the disastrous character of the earthquake was as usual due to the faulty construction of the houses, which consisted of stones with little or no binding of cement. Partly, also, it was due to the comparative immunity of the central district from the great earthquakes of the past, which has allowed such buildings to survive."

The area over which the shock was serious is between 300 and 400 miles long, extending from Poppi (see fig. 1) in the northwest to Potenza in the southeast, and from Rome on the western coast east to the Adriatic sea. It is said to have been felt in the Italian and Swiss Alps, where it caused destructive avalanches; and lighter shocks were also felt in the Tyrolean Alps. The earthquake was recorded at many distant observatories, including those in England and North America, the long waves being recorded at 7:19:21 a.m. at the Harvard station, Cambridge, Massachusetts; at 7:20:5 in Ottawa at the Dominion Astronomical Observatory; and at 7:23:20 at Georgetown University, Washington, D. C., mean Greenwich time. The Denver, Colorado, station of the Jesuit Seismological Service reports that no record was made at that place. Mr. E. F. Davis, of the Seismographic station of the University of California, reports that a barely noticeable disturbance of the writing pen on the north-south component instrument was produced at the Lick Observatory, while at Berkeley a rather poor record was made.

Though the seismograms were poor, they undoubtedly represent the Italian earthquake, as the shock at the epicenter occurred at 6:53 a.m., January 13th, mean Greenwich time, while the first distinguishable wave of the chief phase arrived at Berkeley at 11:39 p.m., January 12th, Pacific Standard Time, or at 7:39 a.m., January 13th, mean Greenwich time. Thus about forty-six minutes were required for the shock to travel from Italy to the Berkeley station, which is nearly the time to have expected theoretically.

Although the number of deaths in this earthquake was not so great as in some others, the percentage of deaths was the highest that has ever been recorded. The highest previous death rate was in the earthquake in 1703 at Norcia, located fifty-five miles northwest of Avezzano, when 81 percent. of the total population were killed, while in 1908 at Messina 65 percent. were killed. The death rate in the town of Cappelle during the recent Italian earthquake, however, was as high as 97 percent. The neighboring city of Avezzano sustained the heaviest loss, 10,719 persons having lost their lives, or about 96 percent. of the total population. Many villages near Avezzano suffered great loss of life, approximately 4,500 being killed at Pescina, 3,300 at Massa d'Albe, 3,300 at Celano, 2,450 at Cenchio, 1,300 at Magliano di Marsi, and 1,000 at Paterno; while Scanno, Campebasso, Sulmona, Popoli, Aquila, Cittaducale, and Monterotondo report deaths, and many other towns within a radius of thirty-five miles of Avezzano suffered severely. The shock was heavy at Poppi, Perugia. and Ferrara; while much damage was done and many people were reported injured at Torano, Atri, Caserto, Sarno, and Potenza. The cities of Rome and Tivoli each report one death and damage to buildings, statuary and other works of art; while Naples was only slightly damaged. The total number of deaths was 29,978, this number not including those who subsequently died of shock, hunger, cold, or wounds.

Railroad bridges and tunnels were destroyed, tracks and wagon roads covered with landslides; and as the district about Avezzano is in part rugged and inaccessible, it was some time before the relief trains and rescue parties organized at Rome, Naples, and the undamaged cities were able to reach the stricken towns. Companies of soldiers were sent out on rescue parties, and saved many people from a slow death under the ruins. The survivors were for many days in a very destitute condition, as snow and rain, with the resulting cold weather and high water, followed the earthquake, adding much to the misery of the people, many of whom were compelled to camp in the open air, while others feared to remain indoors.

The duration of the earthquake was from fifteen to forty seconds, the shock lasting at Rome about fifteen seconds. Davidson states that "near the epicentre, there was one shock of great violence, followed by three others. In other neighboring places, two prolonged shocks were felt. The principal epicentre was no doubt close to Avezzano, probably within five miles of that town. It was in this district that the high death rates occurred. There was apparently, however, a secondary epicentre including Sora, where 500 persons lost their lives, and Isola Liri; and it is possible that the double shock noticed at some places was due to impulses in two corresponding foci, about twenty or twenty-five miles apart."

The highest intensity of the earthquake was apparently in the vicinity of Avezzano, where, judging from the complete destruction of buildings and the reported fissures in the ground, it was X, Rossi-Forel scale. At Sora, Campebasso, Scanno, Sulmona, Popoli, Aquila, and Cittaducale the intensity was probably between IX and X; while in the more distant towns and cities, such as Tivoli, Rome, Sarno, and Potenza the intensity was about IX. The earthquake is said to have been so violent at Naples that the needles on the seismograph at the International Volcanological Institute were broken. Although trustworthy details are scarce, it seems from the data at hand that the isoseismals will be elongated in a northwest-southeast direction, which coincides with the general direction of the structural lines.

More than one hundred after-shocks were reported within twenty-four hours after the earthquake on January 13th, none of them proving to be of a serious nature, however, except one on the morning of January 14th, which caused the collapse of several buildings. On January 19th severe earthquakes were felt in the province of Calabria on the "toe" of the mainland, and in the Ionian islands to the east, but so far as known they caused no loss of life. The shock in Calabria appears to have been most severe in the neighborhood of Cosenza, the capital of the province. On February 15th severe shocks were felt in the vicinity of Avezzano, when Cittaducale, somewhat damaged by the earthquake of January 13th, is said to have been completely destroyed; while a few people were killed in the city of Veroli, south of Avezzano.

CENTRAL CALIFORNIA EARTHQUAKE OF NOVEMBER 8, 1914

By E. F. Davis

At Berkeley, this earthquake was felt by almost everyone except those persons who were walking out of doors at the time of its occurrence. The preliminary tremors were distinctly felt by all those favorably situated for observing earthquake movement, as a barely perceptible trembling motion. They were not, however, generally recognized, at the time of their occurrence, as part of an earthquake. The real nature of the movement was realized only when the waves of the chief phase arrived. Strong movement began with a lurching of buildings accompanied by creaking of the walls and ceilings of frame houses. Small movable objects were not much disturbed by the shock in Berkeley. Though only a feeble earthquake, it produced a feeling of alarm among many people in this locality, and a few of the more nervous left their houses. The intensity in Berkeley is estimated to have been between III and IV of the Rossi-Forel scale.

At the Lick Observatory the earthquake was somewhat more severe. Director Campbell estimates the intensity there as ranging from IV to V of the Rossi-Forel scale. Here also the preliminary motion was distinctly perceptible to those who were favorably situated.

The intensity at various other places in the affected region, according to reports received at Berkeley, is shown upon the accompanying diagram (Figure 1). The information in the hands of the writer does not warrant any attempt to construct the isoseismal lines of this earthquake. The distribution of intensity as shown on this diagram indicates a tendency for the second and third isoseismal lines to be elongated parallel to the trend of the Coast Ranges. Also the intensity appears to die away more rapidly toward the south than toward the north.

The intensity of the earthquake at Santa Clara and at the Lick Observatory was a little too great to permit its satisfactory registration by the sensitive seismographs at those places.

Figure 2 is a copy of the seismogram of the vertical component, obtained at Santa Clara University. The horizontal records obtained there were not complete, the intensity of the shock being great enough to throw the pens off the paper during the greater part of the motion. It is not possible to determine the distance of the epicenter by means of the vertical record at this station. The first preliminary tremors are about as strong as the first part of the main waves. On this account and also due in part to the short period of the vibrations, which causes

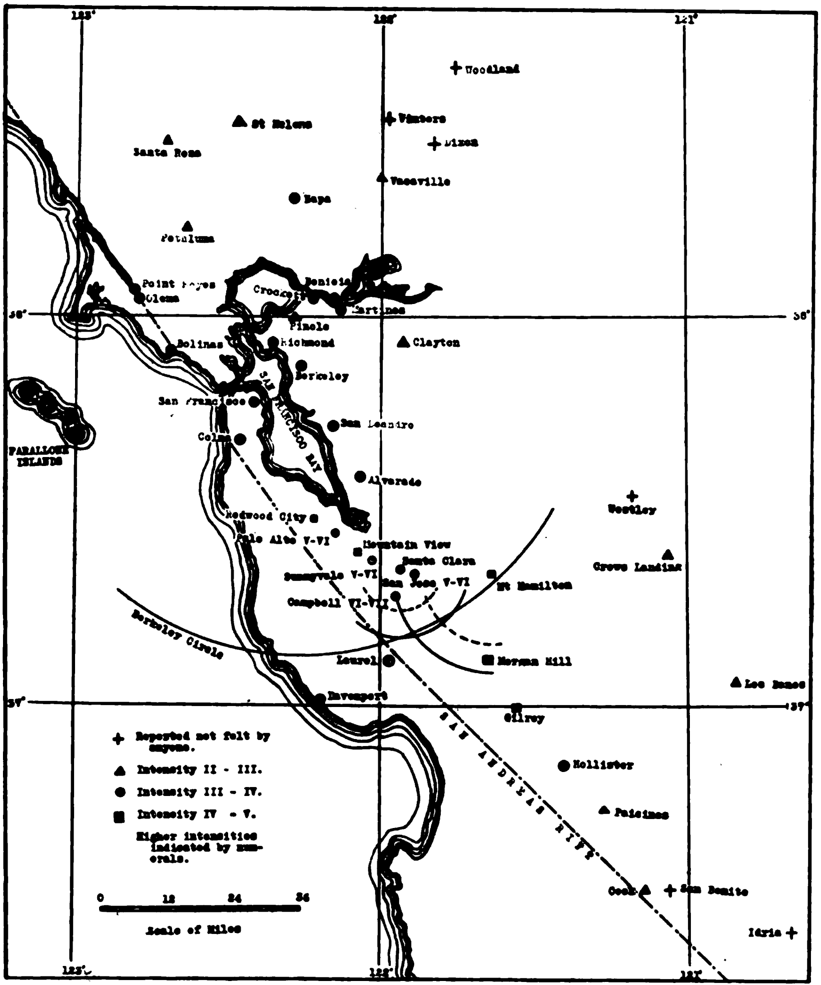

Fig. 1. Central California Earthquake of November 8, 1914.

the records of various impulses to be run together, it is not possible to separate the phases and thus determine the value of the interval *L-P*.

At the Lick Observatory the horizontal pens were thrown off the paper during the last part of the preliminary motion, and remained off during the rest of the preliminary movement and during the first part of the main phase. The vertical record was poor, the friction being so great that the seismogram was not well written, and no phases could be made out.

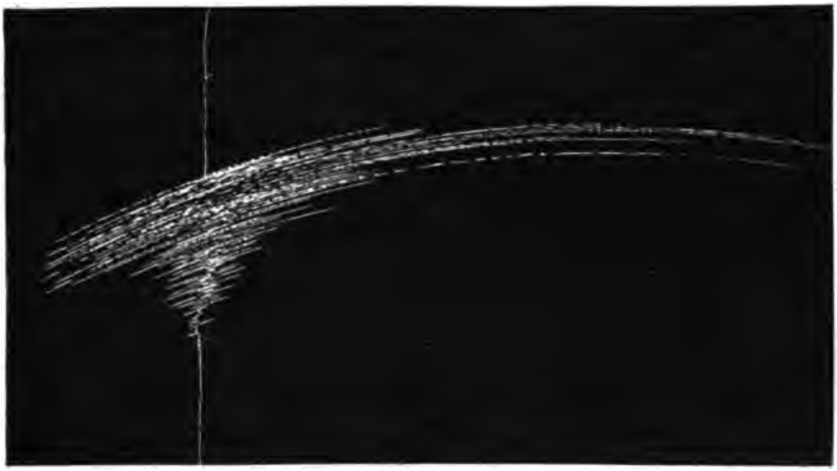

Fig. 2. Vertical Seismogram at Santa Clara Station.

The Berkeley Station was more fortunate in that the intensity at that place was not too great for satisfactory registration. Good records were obtained on all the instruments at Berkeley, with the exception of the Marvin strong-motion seismograph. The earthquake was not sufficiently strong to operate the starting device of this instrument.

Figure 3 is a copy of the north-south component, as obtained by the Bosch-Omori seismograph belonging to the Berkeley station. It will be noted that the first shift of the pen on this sheet was to the south. Also there appears to be a separation of the preliminary tremors into two divisions—possibly representing the first preliminary and second preliminary tremors. Usually it is not possible to find this separation on records of such near shocks.

Figure 4 is the record of the east-west component obtained by the

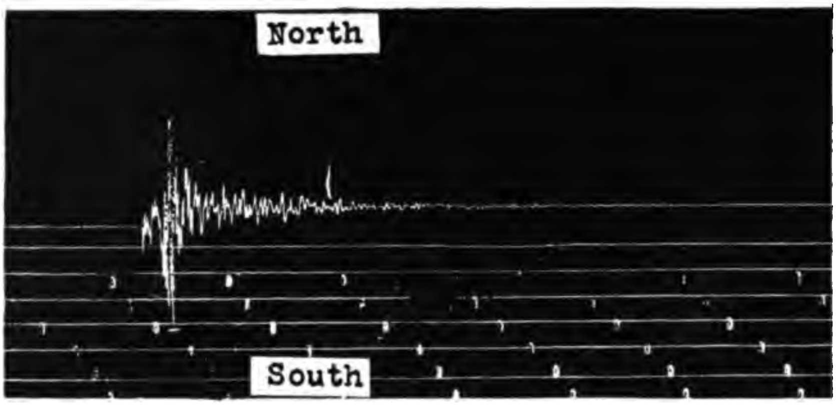

Fig. 3. North-South Component Seismogram at Berkeley Station.

Bosch-Omori seismograph at Berkeley. The separation of the preliminary tremors is quite noticeable here also. On this record the first shift of the pen is toward the east. This is quite distinct on the original record, though the photograph does not bring it out so clearly. The maximum movement occurred in the east-west component. One interesting thing about this record which is probably not very apparent from the photograph is that the lines of the seismogram are "tangled." That is to say, the lines representing successive earth movements cross

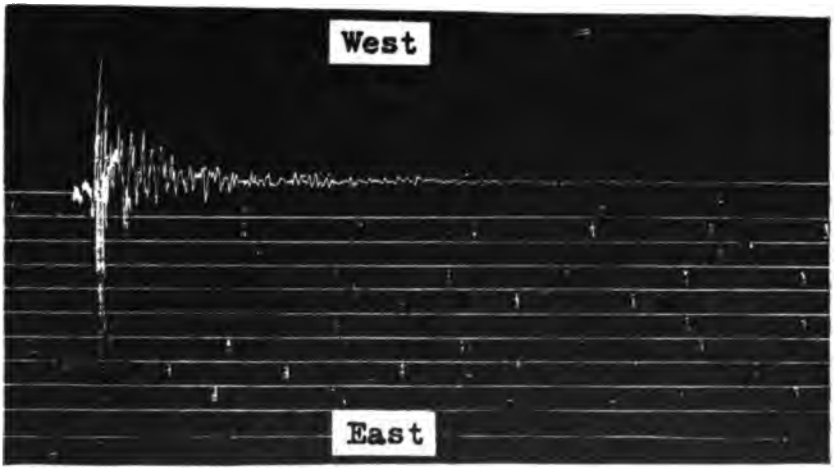

Fig. 4. East-West Component of Seismogram at Berkeley Station.

each other, indicating that there was some differential movement in the mechanism of the seismograph other than that which was due to the registration of the earthquake; so that the intensity here was about the limit for satisfactory registration.

Figure 5 shows the first part of the seismogram obtained at Berkeley by the Wiechert vertical-component instrument. Here the first movement of the writing pen is *down*. The separation of the preliminaries is not apparent on this record.

The maximum acceleration of the ground at Berkeley during this earthquake was estimated to be about 85 millimeters per second per second.

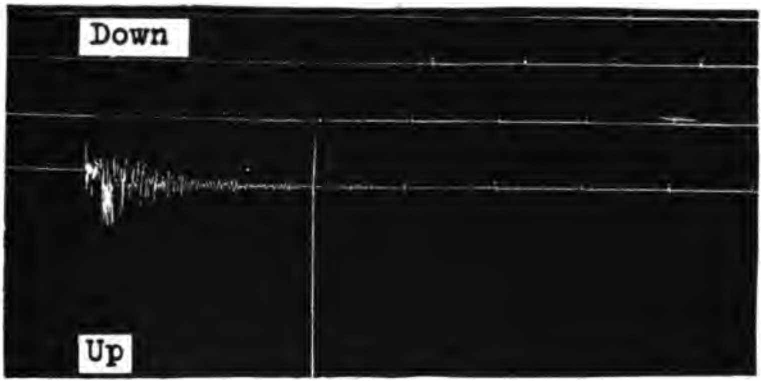

Fig. 5. Vertical Component of Seismogram at Berkeley Station.

From what follows it will be apparent that the origin of this earthquake lay off to the southeast of Berkeley. The fact that the first motion of the ground in this earthquake at Berkeley was *toward the origin* is rather peculiar. Usually tectonic earthquakes begin with a wave of expansion and not a wave of contraction; so that the first shift of the horizontal pens is away from the origin and the first shift of the vertical pen is upward.

The idea is commonly accepted among seismologists that the first shift of the ground in tectonic earthquakes is *away* from the origin, while that of movements due to volcanic earthquakes or to explosions of any sort is *toward* the origin. Thus Dr. Omori,[1] in writing of the Messina-Reggio earthquake of December 28, 1908, says:

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[1] F. Omori: Bull. Japan. Imp. Eq. Investig. Com., 3, (1909), 41.

> Again, according to the seismographic records obtained at the seismological stations of Messina, Catania, Mineo, Mileto, and Valle di Pompei, the direction of the very first displacement of the earthquake motion at each of these places, which was well defined, was *divergent,* that is to say, directed *outwards* from the center. This is rather contrary to what would take place had the earthquake, as popularly supposed, been caused by a violent volcanic explosion in the Strait; since, in the latter case, the initial motion at a place sufficiently near the center of disturbance would be directed *inwards,* the second or counter motion being directed outwards.

In some cases, as for example in the Central California earthquake of July 1, 1911,[2] there has been observed an *apparent* initial shift of the ground toward the origin, at places near the epicenter. However, in these instances, the first shift of the horizontal pens is slightly toward the origin and is followed almost immediately by a sudden reversal of the movement with a strong counter movement away from the origin. In such cases it appears that the first impulse of the earth shock was so rapid that what has been called a "whip effect" was produced. That is to say, the first movement was so sudden that the inertia of the pier came into action and the result was a sudden slight tilt of the upper part of the pier toward the origin, followed by its recovery and movement with the earth.

This, however, does not seem to have occurred in this case. The records are definite and the first impulse was a strong shift toward the origin, there being no minor preliminary shift due to the inertia of the pier.

From the preceding description of the seismograms it is apparent that it was possible to determine the time of duration of the preliminary tremors (interval *L-P*) at the Berkeley station only. The interval there was 11.0 seconds. Using Omori's formula for determining epicentral distances of nearby earthquakes ($x^{km} = 6.86y^{s} + 8.1^{km}$) the distance of the epicenter is found to be 83.6 kilometers or 51.9 miles. The arc of the large circle shown in the diagram is described about Berkeley with a radius equal to 51.9 miles.

In order to approximately determine the position of origin of this earthquake, use was made of the times of arrival of the first preliminary tremors at various stations. The method used is simple in principle though somewhat unsatisfactory in practice. Given the time of arrival of the first impulse of the earthquake at Berkeley station, and knowing the distance of origin from Berkeley, it is possible to determine the time of occurrence of the earthquake at the origin, provided the velocity of propagation of the first preliminary tremors is known. Then if the time of arrival of the first impulse at other stations is known it is possible, by using the proper value of the velocity, to determine the distance of the origin from these stations. When these origin distances have been found they may be used in the ordinary way to locate the origin.

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[2] H. O. Wood: Univ. of Calif. Pub., Bull. Seismographic Stat., 2, (September 5, 1912), 41.

The seismograph clocks at the Lick Observatory and at Berkeley are accurate within 0.1 to 0.2 seconds. Mr. Newlin, of Santa Clara University, who kindly permitted the writer to examine the records obtained there, states that the clock at Santa Clara was corrected at noon on the day of the earthquake and by noon the next day it had lost less than a second, so it was practically correct at the time of the earthquake. The times of arrival of the first impulse of the earthquake at the various stations were as follows:

Santa Clara	6h	31m	09.0s	p.m.
Lick Observatory	6	31	10.4	p.m.
Berkeley	6	31	19.2	p.m.

The difficulty in applying this method is that no very accurate values are available for the velocity of propagation of the first preliminaries through the outer layers of the earth's crust. Also it must be remembered that for earthquakes originating very near the station, as in the case of Lick and Santa Clara, the apparent average surface velocity will be somewhat greater than the true velocity, the exact proportion between them depending upon the depth of origin. In his study of the San Francisco earthquake of 1906, Professor H. F. Reid used a value of 7.2 kilometers per second for the velocity of the first preliminaries. This value had been accepted by Wiechert as approximating the true value. Lately other investigators have given other values somewhat lower than this. K. Hausmann studied earthquakes originating near Aachen and showed that the velocity depended upon the geological structure. His values range from 5.0 to 6.5 kilometers per second. Quite recently Zeissig has obtained a value of 6.3 kilometers per second for the velocity of propagation of the first preliminary tremors of an earthquake originating at Leipzig.

For the earthquake in question it was decided to compare the results obtained by using values of the velocity equal to 7.2 and 6.3 kilometers per second. The distance from the Berkeley station was 83.6 kilometers. Assuming a velocity of 7.2 kilometers per second, it took the disturbance 11.6 seconds to reach Berkeley. The earthquake therefore occurred at the origin at 6h 31m 7.6s, if this assumption as to velocity be correct. The time for the disturbance to travel from the origin to Santa Clara must then have been 1.4 seconds. The distance from Santa Clara to the origin, on the assumptions above made, would then be equal to 1.4 multiplied by 7.2, or 10.1 kilometers, which is equivalent to 6.3 miles. The time required to reach the Lick Observatory was 2.8 seconds. The distance from Lick Observatory to the origin on the assumptions made must therefore have been 20.2 kilometers or 12.5 miles. Circles are drawn upon the diagram (Figure 1) about the respective stations as centers with the epicentral distances just given as radii. These circles are shown in broken lines. It is clear that the velocity 7.2 kilometers per second gives no solution in this case.

Assuming a velocity of 6.3 kilometers per second, it was found that on this assumption the earthquake must have occurred at the origin at 6h 31m 05.9s. The distance from Santa Clara would then have been 19.5 kilometers or 12.2 miles, while the distance from Lick Observatory must have been 28.3 kilometers or 17.6 miles. Circles with these radii are drawn about the respective stations in solid lines. In this case there is an intersection a little to the east of the San Andreas Rift.

It should be noted that in the case of nearby stations, such as Santa Clara and Lick Observatory, the depth of origin is not negligible in comparison with the distance from the observing station. For this reason the average apparent velocity will be higher than that assumed. In consequence of this the circles drawn are probably too small. This will result in shifting the probable position of origin of this earthquake to the south and west of the center of gravity of the triangle of intersection shown upon the diagram.

The probable origin of this earthquake is therefore on the San Andreas Rift a little to the southwest of the point indicated in Figure 1.

The foregoing had been prepared before the writer received the BULLETIN for December 1914. This contained an article by Carl H. Beal, of Stanford University, dealing with this same earthquake. Mr.

Beal has studied the distribution of intensity in the field and has come to the conclusion that the probable epicenter of this earthquake was near Laurel, California. There is, therefore, a reasonably close agreement between the results of field and instrumental study of this earthquake.

University of California,
January 1, 1915.

EARTHQUAKE OF NOVEMBER 8, 1914, IN SOUTHERN CALIFORNIA.

This earthquake occurred at about 3:40 in the morning on Sunday, November 8, 1914. The newspapers gave reports of this earthquake which were misleading in that they gave the time as 3:40 *p.m.* Through an oversight this error was repeated in the last number of the BULLETIN.

Since the earthquake occurred at a time when most people were asleep, very little information concerning it could be obtained. At Los Angeles, Whittier, San Fernando and Montebello in Los Angeles County, the earthquake had an intensity between IV and V of the Rossi-Forel scale. At Avalon on Santa Catalina Island the intensity was between III and IV of the Rossi-Forel scale.

At Arroyo Grande, in San Luis Obispo County, an earthquake was reported as occurring at about 3:30 a.m. on this same date. It had an intensity there sufficiently great to awaken sleepers, and was at least IV and possibly V of the Rossi-Forel scale.

This earthquake was recorded by the University of California seismographic station at Berkeley, and also at the station at Lick Observatory. However, on account of the distance of the origin from these stations the records were rather poor. None of the characteristic phases of the seismogram could be made out, and it was therefore not possible to determine the epicentral distances.

THE EARTHQUAKE AT LOS ALAMOS, SANTA BARBARA COUNTY, CALIFORNIA, JANUARY 11, 1915

By Carl H. Beal

Introduction

The southwestern part of California, including Santa Barbara, Ventura, and San Luis Obispo counties and portions of Los Angeles, Kern, Kings, and Monterey counties, was disturbed by an earthquake on the evening of January 11, 1915. The area over which it was felt was roughly elliptical in shape, the ellipse being elongated in the direction of the Coast Ranges—northwest-southeast. The area of greatest disturbance was found to be in the western part of Santa Barbara county near the town of Los Alamos.

As it was decided to attempt to locate the epicenter by gathering information in the field, nine days were spent collecting the data upon which most of this report is based. The writer wishes to acknowledge his indebtedness to President Branner, under whose direction the work was carried on; to Mr. Roy E. Collom, of San Luis Obispo, member of the Seismological Society of America, who assisted materially in gathering data throughout the San Joaquin Valley oil fields and San Luis Obispo county; and to the people living in the disturbed area, who cooperated with the writer in the most courteous and efficient manner.

Very few reports were sent to the Secretary of the Seismological Society of America, probably on account of the fact that the area most seriously affected is not thickly populated. Most of the information was therefore obtained from personal interviews with the people in the field and by writing directly to people living in the area affected. The long-distance telephone was also used in gathering data, and saved many miles of horseback riding over mountain roads and trails, some of which at this season are almost impassable.

Distribution of Intensities

The outer limits of the disturbed area may be roughly outlined as follows: In the city of Los Angeles, where the intensity was II, Rossi-Forel scale, only comparatively few people felt it; and at Salinas, to

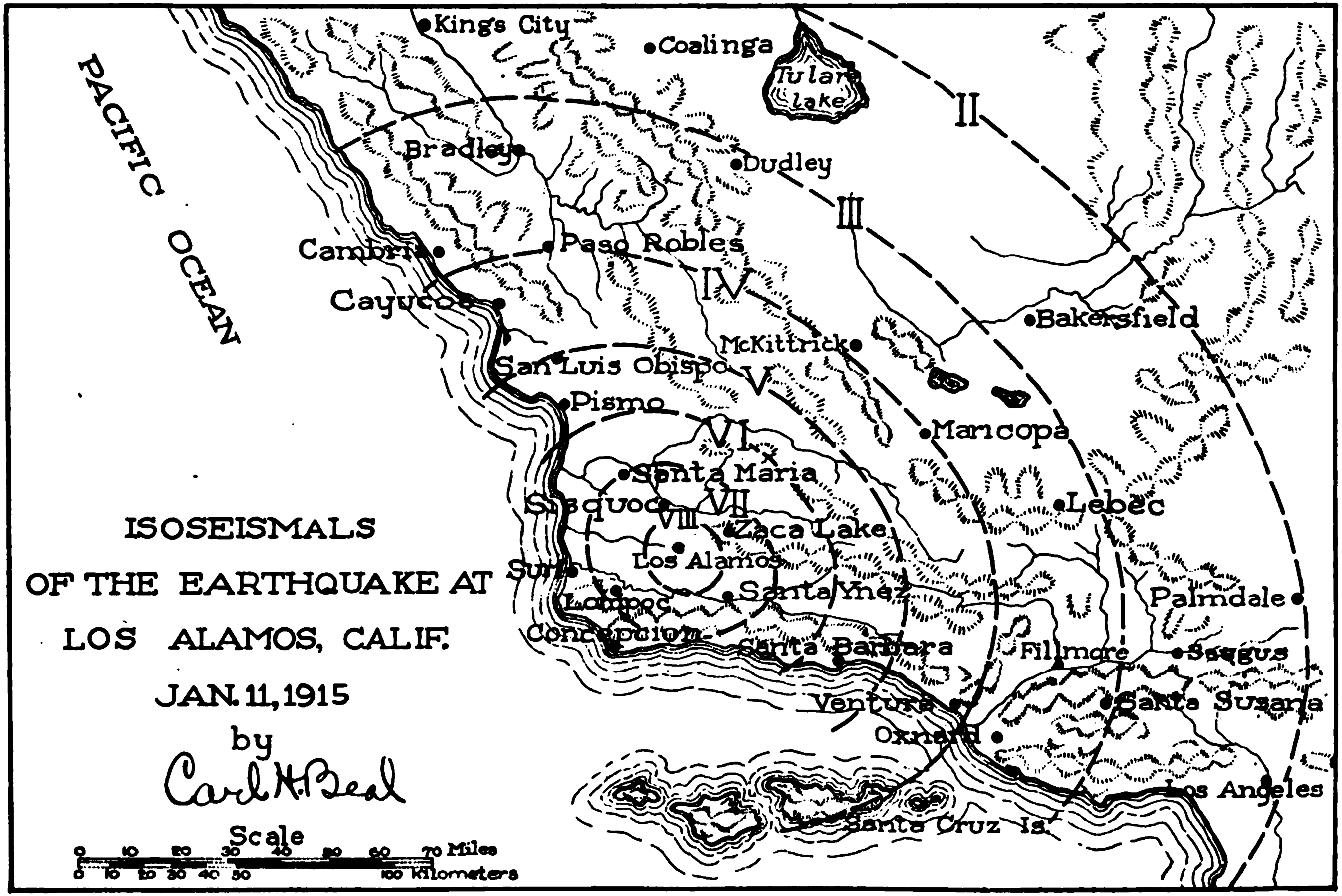
ISOSEISMALS
OF THE EARTHQUAKE AT
LOS ALAMOS, CALIF.
JAN. 11, 1915
by
Carl H. Beal
Scale
0 10 20 30 40 50 60 70 Miles
0 10 20 30 40 50 100 Kilometers
PACIFIC OCEAN
King's City
Coalinga
Tulare Lake
Bradley
Dudley
Cambria
Paso Robles
Cayucos
Bakersfield
McKittrick
San Luis Obispo
Pismo
Maricopa
Santa Maria
Sisquoc
Zaca Lake
Lebec
Los Alamos
Surf
Santa Ynez
Lompoc
Palmdale
Concepcion
Santa Barbara
Fillmore
Saugus
Ventura
Santa Susana
Oxnard
Los Angeles
Santa Cruz Is.
II
III
IV
V
VI
VII
VIII

Fig. 1.

the northwest, the intensity was scarcely as high as II. Frank W. Warthorst, of Bakersfield, member of the Seismological Society of America, places the intensity there at about III. The shock was not felt at Valyermo, a few miles east of Palmdale; but at Lebec, north of Tejon Pass, the intensity was as high as III; at Coalinga the intensity was between II and III.

Within the disturbed area Kings City had an intensity of from II to III; San Luis Obispo, V; Pismo, V-VI; Santa Maria, VII; McKittrick, III-IV; Maricopa, IV; Fillmore, III-IV; Santa Cruz island, IV-V; Santa Barbara, V-VI; Santa Ynez, VII-VIII; Lompoc, VII; and Zaca Lake, VII-VIII. These intensities, in connection with the intensities at many other points about the epicenter, were used in the construction of the isoseismals shown on the accompanying maps. (See figs. 1 and 2.)

LOCATION OF THE EPICENTER

Newspapers reported that the earthquake was rather severe at San Luis Obispo, Santa Maria, and Santa Barbara, while damage to buildings was reported at Lompoc. During the trip south by train a number of people en route to and from various points in the state were consulted and some data were thus obtained. It was noticed by inquiry at the stations at which the train stopped that the intensity became higher in the vicinity of Surf. (See fig. 1.) Approximately the

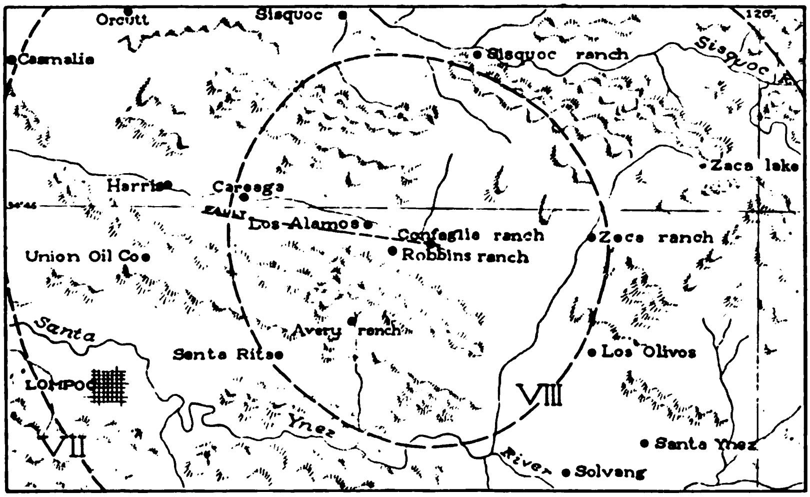

Fig. 2. Epicentral Area of the Earthquake at Los Alamos, California, January 11, 1915. The VIII isoseismal incloses the area over which chimneys fell. Scale: one inch equal to eight miles.

same intensity was found at Point Conception and Gaviota, but it decreased toward Santa Barbara, where the intensity was between V and VI. After obtaining data from towns to the south and east of Santa Barbara by long-distance telephone, a return trip was made to Lompoc, where the intensity was estimated at VII, Rossi-Forel scale. Horseback trips were then made from Lompoc to Santa Rita, Solvang, Santa Ynez, Los Olivos, Los Alamos, Careaga, Harris, Orcutt, Sisquoc, and Santa Maria. Many ranchers were consulted between these places, and it was found that the intensity increased in every case as the vicinity of Los Alamos was approached.

After it was found that the greatest damage was done at Los Alamos, considerable time was spent in locating the area over which the shock caused the collapse of chimneys. The district, though fairly well settled for a mountainous country, has few brick chimneys, practically one-half of the ranch houses having terra-cotta chimneys or a few joints of stovepipe projecting through the roofs. Usually these are wired and braced in such a manner that they would withstand an earthquake of the highest intensity. Again, many brick chimneys have been built for a long time and are in poor condition, while others have been cracked by previous earthquakes. It is obvious that one would experience difficulty in locating the epicenter of an earthquake under such conditions, when the higher intensities are judged from the damage done to houses and chimneys, all of which are of different ages and different types of construction, and where the houses may be as much as six or seven miles apart. The area over which chimneys fell was accordingly inclosed by an isoseismal which is nearly circular, and in this report is referred to as the area of highest intensity. (See fig. 2.)

Diligent search was made to locate some point in this area that seemed to indicate a higher intensity. At the Confaglia ranch, about three miles up the valley from Los Alamos, the dwelling house is a substantially built one-story frame structure about two years old. The ridge-pole of the house lies N. 30° E., and the well constructed chimnew was three feet high and about fifteen feet above the ground. The shock threw the chimney a distance of twenty-six feet in a direction N. 75° E.; while at the Robbins ranch, one and a half miles southeast of Los Alamos, the terra-cotta chimney on the two-story frame structure fell S. 35° W. on the southward sloping roof, and was then thrown about twenty feet S. 75° E. to the ground. These two ranches were shaken much more severely than the town of Los Alamos, not far distant. At Los Alamos, however, the intensity was apparently a trifle higher in the south and east part of town, where the three well built chimneys on the new one-story frame schoolhouse were shaken to pieces and crashed down through the roof into the rooms below. Los Alamos lies in the center of a small valley about one-half mile wide; the Confaglia ranch lies on the north side of the valley and the Robbins ranch lies well within the hills on the southern side. It is estimated that the alluvium upon which Los Alamos stands is much deeper than that upon which the Confaglia and Robbins ranch houses are built.

Cause of the Earthquake

In searching for the cause of earthquakes one turns naturally to a study of the geology of the region in which they occur. The map accompanying the bulletin on the Santa Maria oil district published by the United States Geological Survey[1] shows the somewhat complicated geologic structure of this area to trend nearly northwest and southeast, and a fault striking S. 82° E. is shown traversing the foothills one-half mile south of Careaga. (See fig. 2.) Less than half a mile south of Los Alamos the eastward projection of this fault passes into the alluvium, and if continued would lie directly under the Confaglia house. The Robbins ranch house lies about one-half mile south of this line. Although no surface evidence of movement was found along the fault, it seems highly probable that some underground movement here was the cause of the earthquake. This would account for the fact that the higher intensities were found in the south and east part of Los Alamos and at the Confaglia and Robbins ranches. South of the fault there are no dwellings closer than four miles, besides the one mentioned. The fact that this fault line lies well toward the center of the area of highest intensity is an additional indication that movement along it may have caused the earthquake.

Damage

The actual damage done by the earthquake was not great, and consisted mostly in shattered and overturned chimneys, broken dishes, clocks, and bric-a-brac. In Los Alamos about one-third of the brick chimneys were overthrown, all of which were on the south and east sides of the town. About half of the chimneys were cracked and offset from one to three inches toward the east, while two or three were twisted slightly. Practically every chimney was damaged in some respect. Of the chimneys that fell in Los Alamos and within a radius of three miles, one-half fell in an easterly direction, nearly one-half toward the west, while a few fell southward. Many dishes were broken, and nearly all the clocks were stopped. Most of the clocks which continued to run were on the north or south walls of the buildings. A few water-pipes were pulled apart at the unions, and water was splashed from open reservoirs and watering troughs. The plaster was thrown down from the ceiling and the north and south ends of the church, while a number of kerosene lamps were upset, and at one place four miles south of Los Alamos the house caught fire from an overturned lamp. At Careaga two chimneys were overthrown and a few dishes were broken. At Harris the 8-inch pipe-line of the Associated Oil Company from the Santa Maria field to Gaviota was broken, and about 1200 barrels of oil escaped. The oil was later nearly all recovered by pumping it from depressions in which it had been collected. The same pipe was broken in two places near Santa Rita where the line runs southeast; in one of these breaks the pipe was apparently pulled apart at the union, and the southeast section pushed to the southwest and both sections pushed past each other, so that when found one lapped on the other four or five inches.

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[1] Arnold, Ralph, and Anderson, Robert: Geology and oil resources of the Santa Maria district, Santa Barbara county, California. Bull. U. S. Geological Survey no. 322, 1907.

Dishes were broken and a few chimneys were damaged as far south as the Santa Ynez river; while at the Canfield ranch, five miles east of Solvang and on the south side of the river, two chimneys four feet high were overthrown. Some old chimneys at the Buell ranch on the opposite side of the river were also overthrown. At the town of Santa Ynez dishes were broken and two old chimneys on a house located on low alluvial ground fell. (This point was not included in the area of highest intensity on account of the condition of the chimneys and the character of the ground on which the house stood.) No chimneys were overthrown at Los Olivos, but many dishes were broken. A chimney three miles north, and another four miles northeast of Lompoc were cracked, as were many in Santa Rita and vicinity. At Lompoc the north and south walls of a building made of concrete blocks were cracked. No chimneys were cracked or overthrown, but a few dishes were broken, and bottles and canned goods fell from the shelves in the stores, the shelves from which these articles were thrown usually being on the east or west walls of the building.

The town of Santa Maria, located in the Santa Maria valley, experienced a rather hard shock considering its distance from the epicenter. The plaster was cracked in a few buildings, and the Carnegie Library is reported to have been cracked. In this town and at other points in the same valley dishes were broken and clocks stopped, but no chimneys were overthrown. At Zaca lake the shock broke all the connections on a 16-inch cement irrigating pipe 660 feet long, which was in a tunnel 42 feet underground.

EFFECTS

A number of cracks due to the lurching and settling of the ground were found in a few places. Five miles south of Los Alamos, on the Avery ranch, the alluvial soil in the small valley of Santa Rosa creek was traversed by cracks, some of them four feet wide and six feet deep. (See figs. 3 and 4.) The cracks were near a deeply incised gully about ten feet wide, and were made by the lurching of the ground toward the creek. The area affected was 175 feet long and 125 feet wide, while a small central area 100 feet long and 25 feet wide sank, in some places, from one to three feet. Small landslides occurred in the hills nearby, and less than two miles south a crack from one-eighth inch to three inches wide in very soft sandstone was traced for a distance of 400 feet around the crest of a small hill, which stands about 100 feet above the floor of the valley. Many small cracks were found on the outside of the Santa Rita grade about four miles southwest of Los Alamos, and about ten tons of rock and soil slid and rolled into the road. A similar occurrence was noted on the grade leading up Calaveras canyon, two miles south of Los Alamos.

A small spring of water on the Avery ranch four miles south of Los Alamos is estimated by the writer to have increased its flow to many times its former amount, and it is reported that at Las Cruces, two and one-half miles north of Gaviota, a large sulphur spring flowed twice as much after the earthquake. Some springs ceased to flow, while others flowed in greater volume on the Orania ranch three miles west of Los Alamos. The production of the oil wells in the Santa Maria field was not affected.

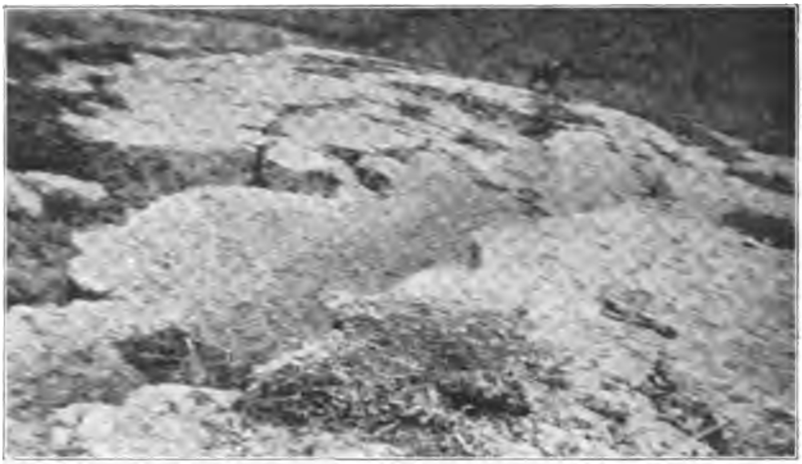

Fig. 3. Cracks in alluvial soil due to lurching. Five miles south of Los Alamos in valley of Santa Rosa creek. (The area in foreground sank four feet.)

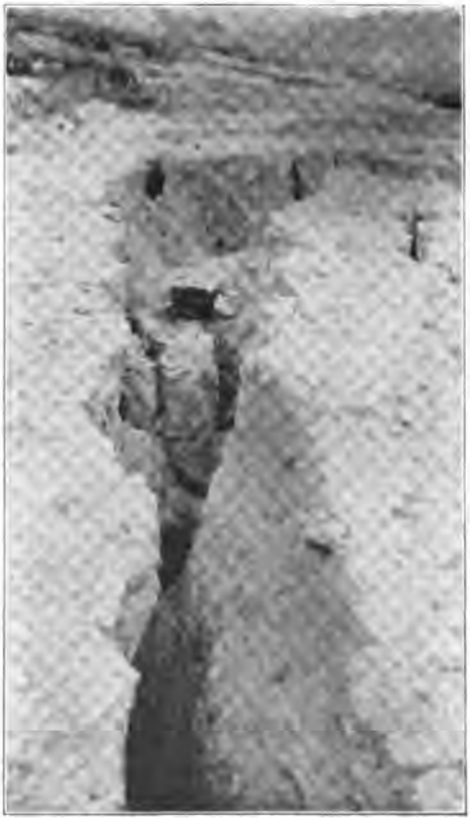

Fig. 4. Detail of crack due to lurching in alluvial soil. Five miles south of Los Alamos in valley of Santa Rosa creek.

Zaca lake (see fig. 2) covers an area of over 19 acres and is 97 feet deep, the ground sloping off very abruptly from the edge of the water. At the time of the shock a tremendous splash was heard by the people living nearby and it was found that the water had been splashed up on the bank a distance of six feet.

The people living in the district that was most seriously shaken were affected in various ways. Two or three women became dizzy and fainted, while practically everybody was badly frightened, and many people ran from their houses. There have been many light shocks since the earthquake of January 11th, and a few people have become very nervous by their constant recurrence.

Some interesting data were obtained in regard to the effect of the earthquake on animals. On some of the ranches not far distant from Los Alamos the horses in the stables became frightened and snorted. The chickens at roost squawked and made a great commotion, while the dogs showed fear and barked. Cats were badly frightened and in a few cases ran out of the house and would not venture inside or eat for several days.

A number of peculiar things, brought to the attention of the writer, may be of interest. On the Robbins ranch two watering-troughs in the barnyard were standing end for end on stakes two feet high. One of these troughs contained a few goldfish and both were partly full of water. The trough containing the goldfish had all the water splashed out and the goldfish were found flopping about on the wet boards in the bottom of the trough. The other trough had little or no water spilled out, and an examination of the supports of the troughs revealed nothing that would account for such a happening. In the ranch-house, one lamp was upset while another of the same kind in an adjoining room remained upright. In Lompoc a jeweler found that one clock on the north wall of his store had stopped and that two others on showcases had been started. At Zaca lake the earthquake is given credit for having started a clock which previously was incapable of running. The swaying motion of the shock started the pendulum swinging, and it is reported that the clock has since kept excellent time.

Some people living upstairs in a brick and cement building in Lompoc possess a buffet, which at the time of the earthquake was standing facing the south, two or three inches from the north wall of the room. On top of the buffet four feet from the floor were two long-stemmed vases containing large bouquets of flowers, while on the buffet shelf one foot above the top rested a large mission-style clock with a broad base. The shock threw the clock six feet south from the buffet but did not disturb the vases and flowers. Near Santa Rita all the cream was spilled off the milk in a number of pans on a large table.

TIME

Accurate information in regard to the time of the earthquake was very hard to obtain, as most of the people on the ranches have poorly regulated clocks. Nearly everyone reported the time as between 8:30 and 9:00 p.m. The clocks at the Southern Pacific stations are set by time signals from Mare Island. The one at Lompoc was stopped at 8:31:30, and the agent at Surf reports that his clock stopped at 8:31:20 p.m., while the government observer in the lighthouse at Point Concepcion reports that the main shock began at 8:32:00 p.m.

Mr. Albert Newlin, of the University of Santa Clara, located about 210 miles northwest of Los Alamos, has kindly furnished the following information in regard to the shock that was registered by the seismograph at that place. The first preliminary tremors were registered on the east-west component of the instrument at 8:31:50, the maximum motion occurring at 8:32:45, while the final tremors ceased at 8:41:00 p.m. We are indebted to Mr. E. F. Davis, of the Seismographic Station of the University of California, for the data in regard to the shock that was registered at Mt. Hamilton. Mr. Davis says in part: "The earthquake of January 11, 1915, began, at the Lick Observatory, at 8:31:49. The maximum motion occurred at about 8:32:50, and perceptible movement of the ground continued until about 8:42. (Times given are p.m. and Pacific Standard Time)."

According to Mr. F. J. Dick the C. D. West seismograph at Raja Yoga Academy at Point Loma, Cal., did not register the shock.

DURATION

Much difficulty was encountered in obtaining trustworthy data in regard to the duration of the perceptible shock. Most persons questioned gave very high estimates, usually over one minute. The government observer at Point Concepcion took the time as accurately as possible under the circumstances and reports that the perceptible shock lasted thirty-two seconds. At Santa Barbara, weather observer George W. Russell reported that the shock at that place was of five or six seconds duration, and at San Luis Obispo the duration was reported by various people to have been between ten and thirty seconds. On the Robbins ranch southeast of Los Alamos, Mr. J. W. Robbins states that the shock certainly lasted at least one minute. The earthquake was without doubt longer than the average, and doubtless the amount of damage done was partly due to the length of the shock.

DIRECTION

Especial attention was paid to inquiries regarding the direction which different observers thought the earthquake shock was traveling, as it has been doubted by many seismologists that such observations are trustworthy. As a rule, people were closely questioned as to *why* they thought they felt the direction given; and the usual reasons were, because a certain corner or side of the house was struck first by the shock; tables, beds, or pianos rolled in the direction given; or because the house was felt to sway and chandeliers swung in that direction.

More than one-fourth of the people questioned within the area over which the disturbance was felt reported that no direction had been observed. Of the 65 observers who felt the direction, 64 per cent gave approximately the direction which on the theory that the earthquake waves travel outward in every direction from the epicenter, should have been felt at the locality of the observer. At Santa Barbara about one-half the people consulted gave the direction at right angles to the one that the shock must have traveled, while of the people who felt the direction at Lompoc, one-fourth gave the correct one, one-half gave the direction within 45°, and one-fourth gave the direction at right angles to the one in which the wave traveled. No one in San Luis Obispo gave the correct or nearly correct direction, and at Point Concepcion the government observer stated positively that the earthquake was traveling west. At Los Alamos and within a radius of two miles observers gave almost every direction on the compass.

From the foregoing it is apparent that data furnished by inexperienced observers in regard to the direction of an earthquake shock is of but little value in determining the epicenter of an earthquake.

SOUNDS ACCOMPANYING THE EARTHQUAKE

Nearly everyone in the area studied in detail heard some sort of sound, either before the earthquake was felt or during the shock, and in a few cases observers claimed to have heard a rumble dying away in the distance after the last tremor had been felt. In Los Olivos the noise is said to have been similar to that of an automobile racing against a heavy wind, while in Lompoc it was described by one man as sounding like an explosion of dynamite, and at Zaca lake it was described as having been similar to that of a siege gun a few miles underground. No noise was heard farther north than Pismo, where a dull rumble was heard; or farther south than Santa Barbara, where a very low sound was heard by about one-tenth of the people consulted. One observer at Los Alamos reports that he heard a "hideous rumble," and another in the same place reported that the rumble was "very loud." The noise seemed to have been noticed by practically all the people in Los Alamos and in the low hills lying north of the town. The sound was apparently confined to the area of the high intensities, as no one reported noise outside the V isoseismal. At Sisquoc, Careaga, Casmalia, and the Dutard ranch, twenty miles north of Sisquoc, a dull rumble was heard from one to three seconds before the earthquake was felt. A rumble was heard to precede the shock by a man three miles north of Lompoc and by four people near the town of Orcutt, while three people in Los Alamos, one man in Sisquoc and one at Careaga noticed the same phenomenon. An observer five miles south of Harris claims that all the earthquakes that have been felt since the one on January 11th have been preceded by a rumble.

Description of the Shock

At San Luis Obispo there were three distinct maxima in the shock which lasted about ten seconds; while Mr. George W. Russell, the government weather observer at Santa Barbara, reports that nine shocks were felt about one-half second apart. Two separate shocks were reported at Lompoc, each lasting about fifteen seconds, the former traveling west and the latter, which was the more severe, southwest. One person interviewed at Lompoc states that he was walking along the street when the doors, windows and all the buildings rocked east and west. He felt no shock but heard a loud roar above the creaking and rattling of the buildings. Another gentleman was looking west along the street at the time of the shock, and, by the light of the street lamps, saw waves traveling rapidly westward. He reported the waves to have been quite similar to those on a body of water, but traveled with great rapidity and were about six inches high. At Los Alamos the shock was described as a series of hard jerks in different directions, with one final vertical jolt. On the Painted Cave ranch, thirteen miles northwest of Santa Barbara, the shock was described as being similar to that produced by a large animal rising up under the house.

Most of the sailors who were asleep on board a schooner six hundred feet from land on the north coast of Santa Cruz island were suddenly awakened by a trembling of the ship as if it had gently run aground. Those who were on deck could see or hear no waves, and estimated that the trembling lasted three or four seconds.

Previous Earthquakes

The district studied is subject to earthquakes, and they have been recorded since the beginning of the nineteenth century. One of the most disastrous occurred the morning of December 21, 1812, when La Purisima Concepcion mission was totally destroyed, and the hill at the foot of which the mission had been built was split by a large crack from base to summit. Another severe earthquake was experienced in the summer of 1902, when the town of Los Alamos was almost completely destroyed.

It is estimated that for thirty days following the earthquake of January 11, 1915, one to three shocks daily have been felt over the area of greatest intensity, but none of these have been of long duration or have done damage.

THE UNTRUSTWORTHINESS OF PERSONAL IMPRESSIONS OF DIRECTION OF VIBRATIONS IN EARTHQUAKES

By John Casper Branner

The blank recording cards sent out by the U. S. Weather Bureau for the use of observers in reporting earthquakes, have a line for reporting "direction of vibration." The appearance of this request may serve as a part of my excuse for calling attention to the fact that personal impressions regarding the direction of earthquake vibrations have no value. The chief object of all such records has been to enable seismologists to locate the epicenters of the earthquakes. It is true that it has long been the custom in recording non-instrumental observations to set down something about direction. Perhaps I should say, rather, that observers have been asked to state the direction of vibration, and even the Rossi-Forel scale says that intensity III is "strong enough for the direction or duration to be appreciable." Observers therefore feel that something of the kind is expected of them, and they make honest efforts to abstract from their sensations some idea of direction; such at least has been my own experience. For years I have tried at every possible opportunity to get some definite impression of the direction of vibrations, but always without any trustworthy results.

When an earthquake is felt all my senses are instantly on the alert, but I generally perceive only the heaving and swaying of the building, the creaking of timbers, the rattling of windows, and all the disturbances about me. The impression received from these jolts, lurches and swayings is too confused to be of the slightest use in determining the direction of the waves which we attribute to earthquakes. Earthquakes felt when in bed do sometimes feebly suggest movements parallel to the sides of the bedstead, but the sides of the bed are parallel to the sides of the house, and the house must of a necessity move on one of its axes as Davison, Forel, and Montessus de Ballore have all long ago pointed out. I have tried to find out how other persons are impressed in regard to this question of direction, and those in whose judgment I have the greatest confidence are unanimous in stating that they are unable to detect any definite direction of motion. The general impression seems to be one of confusion, anticipation, and curiosity, produced by complicated jolts, jars, and shakes, but all without any well defined idea of direction.

The language used by observers is of interest in this connection. One man says the sensation was very like that of a person in a hay-wagon being driven over a street paved with cobble-stones. Another one felt as if the house were being shaken as a terrier shakes a rat. Another was pitched about as if in a boat on a very choppy sea. It is worthy of note that none of these similes suggests direction, but all of them refer to quick, jerky, complex movements.

My efforts to get a sense of direction out of my own sensations have not been entirely abandoned, but my expectations of getting anything of value out of them have practically reached the vanishing point, and I am now, after twenty-three years of honest endeavor, disposed to look with much suspicion on all directions reported from non-instrumental observations.

A sharp distinction must be made, however, between personal impressions and the records made by instruments. Seismographs of the Bosch-Omori type are so made that their very construction is based on the theory that the arms are affected in accordance with the angle at which earthquake waves strike them. Even the pendulum seismographs record the various movements in a horizontal plane. But seismographs record mechanically, and are sensitive even to microseisms that we cannot feel. It follows that in the case of non-instrumental records one can never be quite sure about the exact point in time at which he becomes conscious of an earthquake shock; and by the time the shock has become distinctly perceptible to the observer the movement is usually complicated, and is producing the effect of a jar rather than of a wave-like motion.

In connection with this matter of direction of vibration and direction of epicenter, much was formerly made of the direction in which objects were overthrown. My own observations of things overthrown lead me to attach very little or no importance to the direction in which they fall. In the California earthquake of 1906 a vast amount of data was collected on this subject. Statues, monuments in cemeteries, chimneys, and loose and unstable objects generally, were thrown in every conceivable direction. The direction in which such things fell was determined much more frequently by some accident of mounting, such as the shape of its base, than by the direction of any particular earthquake waves.

It is hardly worth while in this place to enter into the history of the theory of personal impressions of vibration, and of the attempts to draw conclusions from such impressions. It is simply the old story of human endeavor to learn something about a phenomenon that has so long seemed a mysterious force of nature. It was proper enough to try out every suggestion, but this particular theory concerning human perception of the direction of earth-waves having now been pretty thoroughly tried out and found useless, it is time to set it aside.

It will be asked why it is, then, that so many persons who feel an earthquake are aware of some sense of direction of the vibration. The question is answered by Dr. Charles Davison in his account of the Hereford earthquake of December 17, 1896. At page 225 of his "Study of Recent Earthquakes," London, 1905, he says that four hundred and sixty-nine observers made notes of the direction, and he notes that "When those directions are plotted on a map of the district, it is seen at once that they are either nearly parallel or perpendicular to the roads in which the observers were living; that is, the apparent direction of the shock was at right angles to one of the principal walls of the house. This of course is a result to be anticipated, for, whatever be the direction of the earthquake-motion, a house tends to oscillate in a plane perpendicular to one or other of its walls."

There is nothing new about the conclusions reached in this brief paper. Montessus de Ballore in his "Science Seismologique," Paris, 1907, devotes all of chapter II, pages 63-82, to this subject. He there points out that Forel, after a study of the earthquake observations made in Switzerland from 1876 to 1880, concludes that "not only are the directions noted by observers influenced by the facades of the buildings they are in, but in nine cases out of ten the direction is determined by a street." It hardly seems necessary to go into further details; Montessus de Ballore's conclusion is that "information regarding direction should be excluded from earthquake catalogues" (page 82).

Resumé of Conclusions.

1. There is no clear or uniform idea of what is meant by the direction of vibration as determined by non-instrumental observations; some persons regard it as the direction of transmission of a wave-like movement along the surface of the earth; others regard it as a to-and-fro movement like the gentle balancing of a rocking-chair.

2. The sensation at the time of an earthquake is commonly a confused tremulous one produced by jar rather than by wave-like motion having direction recognizable through personal sensations alone.

3. The overthrow of objects shows that the disturbance of equilibrium has very little regularity, and that it bears no definite relation to the direction of movement as indicated by instrumental observation and by other evidences.

4. In many cases where the epicenter is known and the individuals over the area affected have stated their impressions of direction, these impressions are found to be quite useless for purposes of locating the epicenter or for any other purpose, so far as I can see at present.

5. Instrumental records show that the directions are many and the movements complex. Out of such entangled movements it seems quite impossible for our uncertain impressions to gather trustworthy conclusions regarding the location of epicenters.

SEASONAL PERIODICITY IN EARTHQUAKES

By William A. Spalding

Mr. Stephen Taber's study of earthquakes in the region of Charleston, South Carolina, during the period 1886-1913[1] is a valuable contribution to the data and theory of seismology. I am particularly interested in his discussion of periodicity in earthquake frequency, as that is a phase to which my attention has been directed during the past twenty years. Mr. Taber's curves are deduced from a monthly distribution of the 395 earthquakes under observation, and are analyzed mathematically for annual, semi-annual and quarter-yearly periodicities, using the methods adopted by Dr. Knott. The study is made more interesting by dividing the entire period into two epochs: first, 1886-1897, with its record of 318 earthquakes; and second, 1898-1913, with 77 earthquakes. While the investigator concedes that the number of earthquakes in the latter interval is too small by itself to be of value in determining periodicities, still the fact that the two curves thus separately deduced correspond closely in their characteristics lends additional interest to the study and is mutually confirmatory. This double testimony is again confirmed by curves based upon earthquake-days during the same intervals, thus eliminating a number of minor shocks and reducing the problem to a simpler basis. Mr. Taber's conclusions are as follows:[2]

"There is probably no real semi-annual periodicity in the earthquake activity of this region (Charleston, S. C.). Annual and quarterly periodicities are indicated, though the data are most too meager to determine this matter with certainty. However, the marked similarity of the different curves strongly supports the hypothesis that there are real annual and quarter-yearly periodicities."

My purpose is writing this is to institute another seasonal comparison, varying slightly from Mr. Taber's, but utilizing the same data of monthly distribution. I divide the year into seasons relative to the earth's equinoctial periods, and the intervening solstices. This, of course, suggests a line of causation not considered by Mr. Taber in his paper, and involves a theory not yet established. Still it is worthy of investigation on a strictly physical basis such as I propose, and if periodicity is indicated empirically, we may bring forward the theoretical part of the discussion at leisure. I have merely to suggest at the outset that, the equinoxes themselves being periodical, if we succeed in allying earthquakes with them in any degree as effects or as concurrent phenomena, we shall have gone a long way toward solving the standing problem of seismic periodicity.

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[1] "Seismic Activity in the Atlantic Coastal Plain near Charleston, South Carolina," a paper read in part before the Le Conte Scientific Society at the University of South Carolina February 6, 1914, and published in the *Bulletin of the Seismological Society of America,* 4, 108, September 1914.

[2] Ibid., p. 123.

The vernal equinox occurs March 21st. Allowing that there may be some relationship between this occurrence and seismic action, it is fair to assume that the equinoctial influence begins some time before the actual event, and continues some time afterward. Let us assume, for convenience, that the period of greater or less equinoctial influence is three months, beginning February 1st and ending April 30th. This would allow 48 or 49 days before the equinox and 40 days after it. Granting this amplitude for the season of the vernal equinox, we should surely find indications of seismic increase or decrease within it if there be such a tendency developed in the curves.

In a similar manner we set off the months of August, September and October as the season of the autumnal equinox. The intervening seasons of three months each are allotted to the summer and winter solstices, and we have the year divided as follows:

Season of vernal equinox—February, March, April.
Season of summer solstice—May, June, July.
Season of autumnal equinox—August, September, October.
Season of winter solstice—November, December, January.

When we come to consider the year thus divided with respect to seismic frequency, the only striking variation from the plan usually in vogue is that the year begins with February, and January comes trailing along after December, as it in fact always does in the natural round of years. The advantage of this readjustment is simply to bring out in our diagrams the equinoctial and solstitial effects, if they exist, in stronger relief.

Re-drawing Mr. Taber's most typical curve from his plate 7 (that of total South Carolina earthquakes during the years 1886-1913), we have the following:

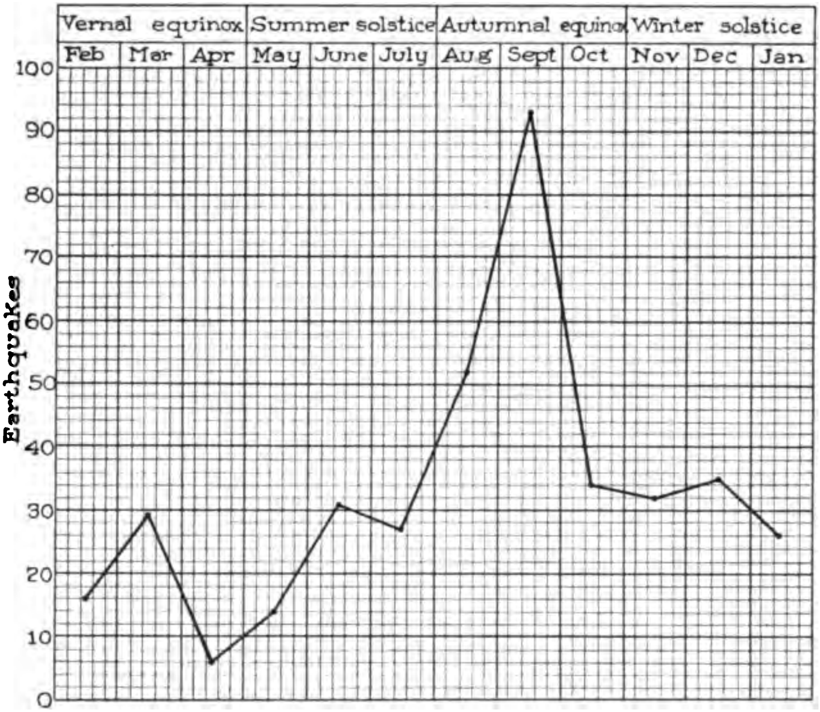

Fig. 1. Monthly Distribution of Earthquakes. Charleston Statistics. Total 395.

In figure 1 we have almost a facsimile of figure 5, plate 7, in Mr. Taber's drawing, but with our new adjustment of seasons the curve takes on an increased significance. In short, the line seems to be exactly fitted to the seasonal scheme. Here we have the maximum frequency in the middle of the period assigned to the autumnal equinox, and a minor rise in each of the other three seasons. The special advantage of this plan is that it is based on a previously assigned system; that this system is formed on well established periodic phenomena; that we may reproduce the formula for any year; that, if this concurrence of seismic frequency with the seasons assigned is sustained by a preponderance of testimony, it points toward a generalization of value, and that, behind that generalization, there may lie a good and sufficient reason for seismic periodicity.

Let us proceed to other statistics of earthquakes which may be subjected to the same test. The oldest table of seismic frequency by months which I have at hand is one quoted by Dr. Mallet in his treatise on earthquakes in the British report for 1850, p. 66. It is referred to by Dr. Mallet as having been compiled by L. F. Kontz and originally published in the Allgemeine Encyklopädie der Wissenschaften und Künste, von Ersch und Gruber, Thiel, 36. This list, compiled by a German authority previous to 1851, comprehends a different series of earthquakes, and must be taken as independent of the data employed by Mr. Taber.

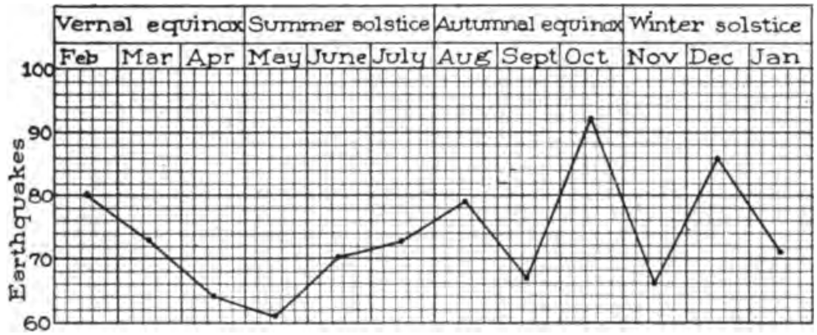

Fig. 2. Monthly Distribution of Earthquakes. German Statistics. Total 882.

Here we have a curve not so striking as that shown in figure 1 but still showing the same characteristics, with the maximum in the season of the autumnal equinox and minor rises in the three other seasons. It should be borne in mind that the old data employed, while gathered from a much wider field and comprising a larger number of earthquakes, is probably less reliable and complete. The curve formed upon the Charleston data, gathered in a single restricted and well defined seismic area, and doubtless more accurately compiled, ought to be the better testimony, furnishing the more typical curve.

For a third trial, we turn to another distinct and far-distant field, this time employing statistics compiled by Baron Dairoku Kikuchi, and published by the Japanese Imperial Earthquake Commission in its Report No. 19.

Here again we have the same general characteristics in a modified form and with sufficient variation to make the study interesting. Still the maximum point is in the autumnal equinox. See figure 3.

Again we shift the field and take data of Pacific Coast earth-

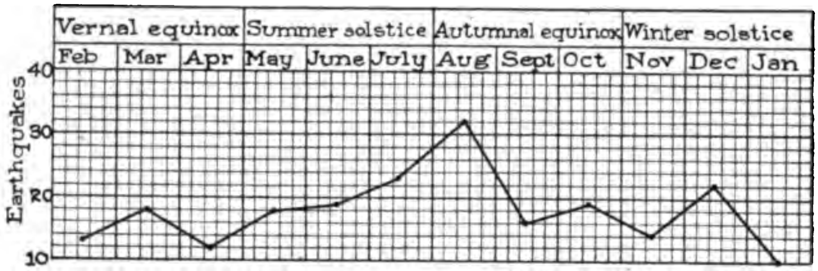

Fig. 3. Monthly Distribution of Earthquakes. Japanese Statistics. Total 216.

quakes from 1850 to 1887 inclusive, compiled by Professor E. S. Holden and published by the Smithsonian Institution, 1898:

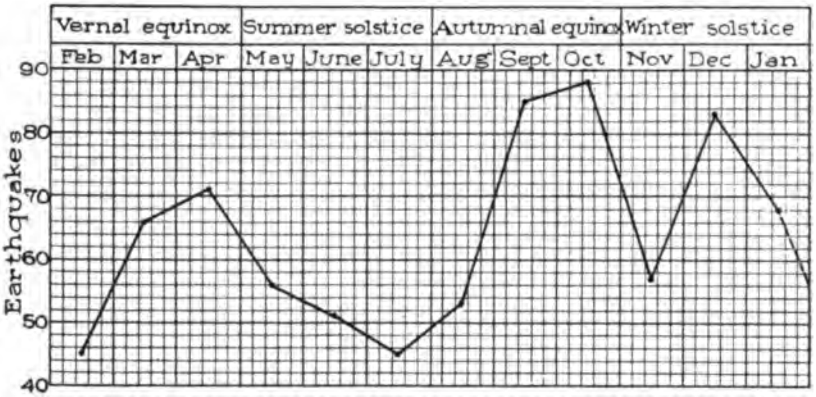

Fig. 4. Monthly Distribution of Earthquakes. Pacific Coast Statistics. Holden. Total 768.

In 1907 the Smithsonian Institution published Professor Alexander G. McAdie's "Catalogue of Pacific Coast Earthquakes from 1897 to 1906," as a supplement to Professor Holden's catalogue referred to above. Professor McAdie's catalogue includes the great San Francisco earthquake of April 18, 1906. Upon a monthly distribution of this list we obtain the curve shown in Fig. 5.

While we have given no extra value in the statistics to the earthquake of April 18th, counting it simply as one, the large number of after-shocks swells the record considerably for the vernal equinox and for all the later months. The uplifts in the curve for the vernal equi-

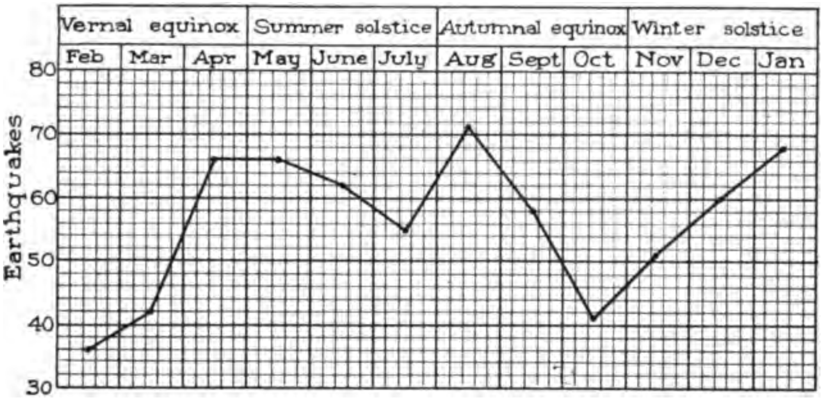

Fig. 5. Monthly Distribution of Earthquakes. Pacific Coast Statistics. McAdie. Total 676.

nox and the summer solstice (figure 5) are exceptional, and might become confusing were it not for the special justification therefor.

We now venture upon the most extensive and most crucial test of all. From Mallet's "Catalogue of Earthquakes," published in the British Association Reports for 1852-3-4, I have collated monthly data of 5155 earthquakes, which occurred from 1600 to 1842 inclusive, the catalogue being based on authentic reports from every known field on the earth's surface. From these exhaustive data we obtain the following diagram.

This curve, figure 6, is strongly emphasized, but does not depart to such an extent from the characteristic line already developed as to form a contradiction. The minor rise in the summer solstice previously developed disappears, and is replaced by a decided minimum at that point. For this we had a precedent in figure 4.

In fact this latest development, figure 6, corresponds so closely in essential features with those previously secured that I feel warranted in making a composite of the whole series.

Figure 7 includes all of the statistics embraced in figures 1, 2, 3, 4, 5, 6.

Here is the summary of our study—the conclusion which must be relied upon to give the characteristic curve. If this curve has any significance, it is to show that there is some concurrence between the earth's solstices and equinoxes on the one hand and earthquake frequency.

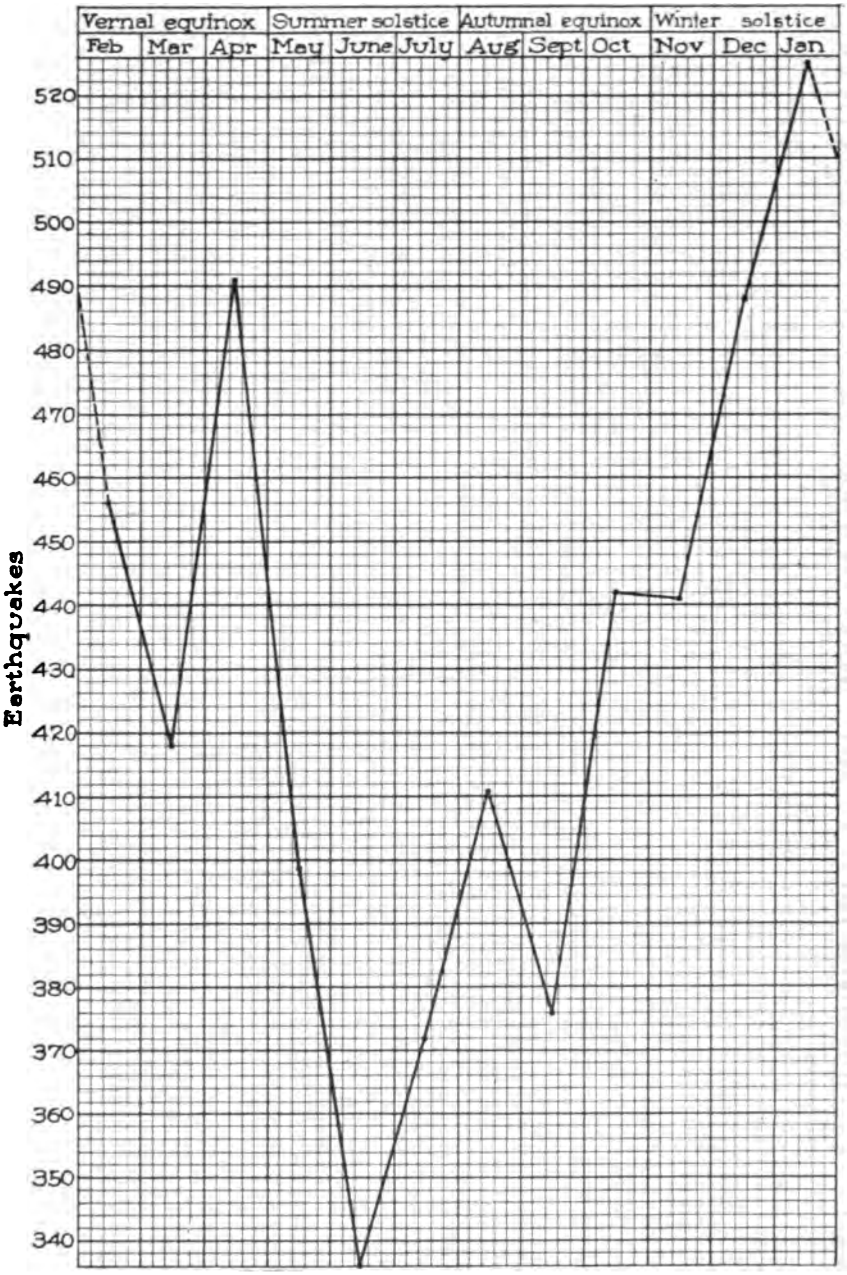

Fig. 6. Monthly Distribution of Earthquakes. English Statistics. Total 5155.

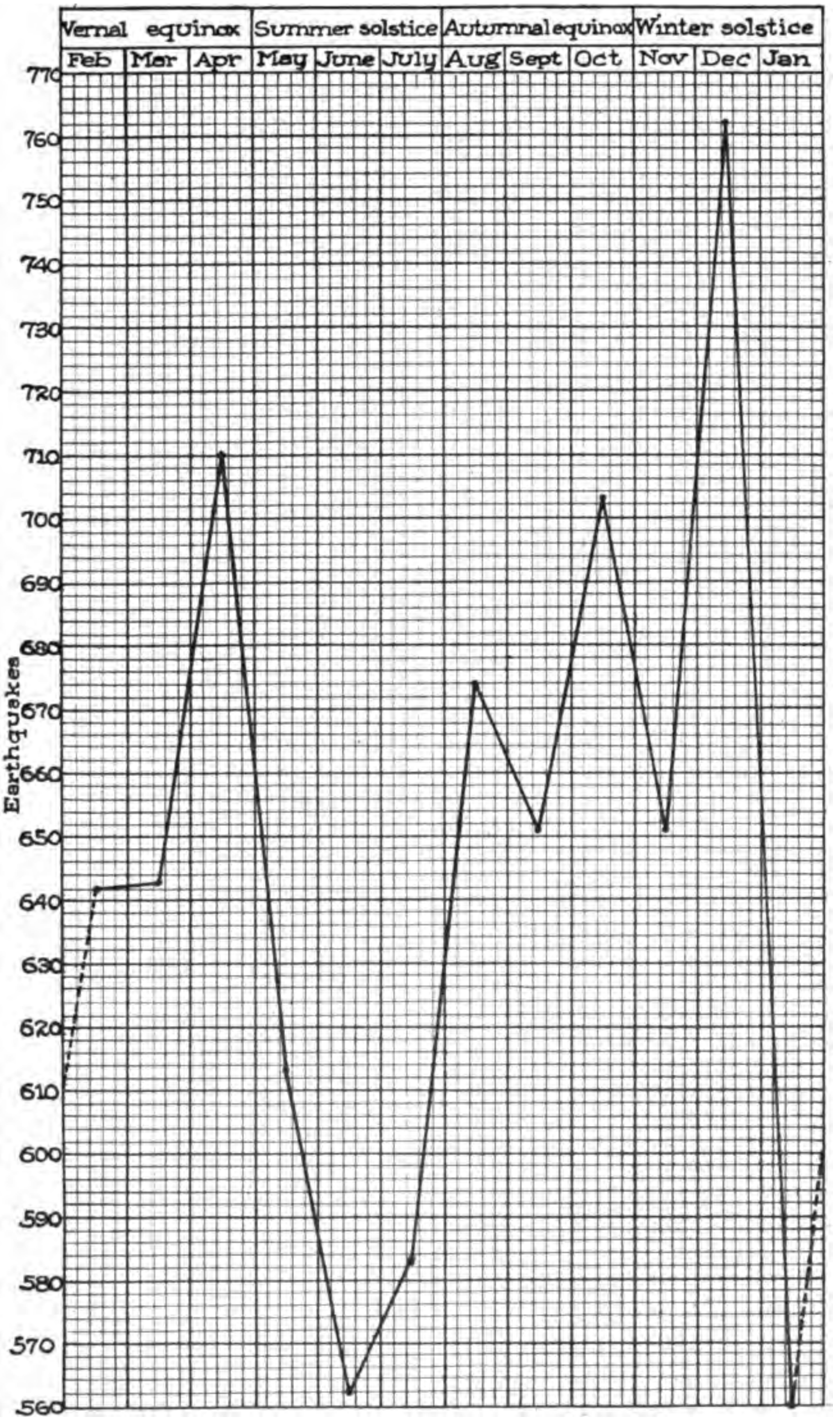

Fig. 7. Monthly Distribution of Earthquakes. Combined Statistics. Total 7754.

In other words, whatever constant or measurably recurrent fluctuation may be shown to exist at those seasons points toward periodicity. Since the earth's equinoxes and solstices are simply phases in the inter-adjustment of the earth to the sun in the course of the earth's annual revolution, we are warranted in investigating those phenomena, to ascertain whether such readjustments may involve physical action that influences to some extent seismic frequency.

Los Angeles, Cal., January 11, 1915.

THE SEISMIC PRELUDE TO THE 1914 ERUPTION OF MAUNA LOA

By Harry O. Wood

After a quiet interval of nearly eight years the great volcano, Mauna Loa, in the southern part of the island of Hawaii, again broke into eruption on November 25, 1914. Action began in the early afternoon, probably, in the summit sink-crater, Mokuaweoweo. So far as yet ascertained the outbreak was first seen between noon and one o'clock, approximate local time, by herdsmen on the Kapapala ranch at work at an altitude of about 6,000 feet on the southeastern slopes of the mountain. They saw white fumes rising above the mountain summit. Correlative with their discovery, some twelve or more local earthquakes were registered in the Whitney Laboratory of Seismology, at the Hawaiian Volcano Observatory, in a short interval beginning a little after noon. These are discussed below.

At about 4 p.m., approximate local time, residents at Pahala noticed rising columns of white, or bluish-white, fumes appearing above the summit of the mountain, one by one, progressively from the northernmost southward, until five well-defined columns were seen rising continuously. The outbreak was first noticed at the Observatory by the writer at about 6:15 p.m., Hawaiian Standard Time (meridian of 157° 30′ Long. W. from Greenwich), as a startling and very brilliant glow directly above the mountain summit, seen somewhat vaguely through a curtain of driving mist which had obscured the mountain throughout the afternoon. Later in the evening the illuminated fume columns winding upward to merge and spread out at an elevation of 6,000 to 8,000 feet above the summit (20,000 to 22,000 feet above sea), made a scene of great beauty and magnificent proportions.

Visits to the summit later determined that, as in former instances, molten lava was ejected there by a process of fountain action such that magma jets sprayed upward—at maximum possibly more than 300 feet—from several orifices within the central depression of the great caldera. These jetting places appeared aligned along the course of the well-known NE-SW rift through the mountain. Around the orifices miniature cinder cones were built.

At the Hawaiian Volcano Observatory this eruption was preceded by a sequence of very light local earthquakes—in character like those that are all along being registered here—which had been occurring with unusual frequence during two months or so previous to the outbreak. More than one hundred shocks were recorded during this interval, of which seventy-two took place during the first twenty-five days of November. But very few of these were felt either here or elsewhere in the island. Nevertheless, perceptible shocks had been somewhat more numerous than usual, and this led to a vague current opinion among old residents that eruption was impending. Also for this reason, and others as well, an outbreak was anticipated by the staff of the Observatory. *Notwithstanding this, no markedly unusual circumstances* attended the occurrence of these shocks, and their intensities were low in every instance.

Unfortunately, about the middle of August 1914 it became necessary to suspend seismic registration in the Whitney Laboratory to allow of repairs, renovation and improvements. Unforeseen delays in the accomplishment of this work led to a protracted suspension of registration—through a much longer interval than had been anticipated. It had not been resumed on the morning of September 27, 1914. During this interval of about six weeks no earthquakes were felt at the Observatory. However, in other parts of the island several very light shocks are said to have been felt; but no systematic reports are received here from such outlying sources, and there are no adequate press accounts of such occurrences. Hence these shocks are not on record at this Observatory.

On the morning of September 27th, while at work in the Observatory, the writer's attention was drawn to the occurrence of a shock by the audible starting of a seismograph power-clock which was wound, trigged and in circuit for magnetic release with a very sensitive electric starting device. Though not sensibly perceptible in the Observatory, this earthquake was of considerable amplitude *instrumentally*. Though none were recording, all the seismographs had been reinstalled and in large measure re-adjusted, so that they were nearly ready for the resumption of registration. On one of them the light, magnifying, writing lever had been put in position. This was observed to be swinging rapidly—with a period of about a half-second—through arcs as large as the mechanism would permit. What is more, this earthquake, or sequence of them in rapid succession, maintained for more than a minute so strong a vibration in the earth that the sensitive electric starting device kept making and breaking circuit, rendering it impossible during this interval to stop and re-set the power clock. At length this was accomplished; but, hardly done, another shock occurred strong enough to set it in motion again, and again for a short interval it was impossible to stop and re-set it owing to the continued swinging in and out of circuit of the starting device. This shock also was not of perceptible strength at the Observatory.

These shocks occurred at approximately 10:06 a.m. H. S. T. and 10:08 a.m. H. S. T. They were felt as moderately strong shocks of the weak-shock class at points from fifteen to twenty-five miles southwest from the Observatory, and less forcibly at nearer places.

Partial registration was at once resumed, and within a few hours all the seismographs were again at work. The seismic spasm continued. Except for an interval of a little more than two hours in the forenoon of September 28th, utilized in making re-adjustments and writing test seismograms, there was no further interruption of registration. No shocks occurred during this brief interval, for at least one of the seismographs was always writing. But during about forty-eight hours—from 10 a.m. H. S. T. on September 27th to the same hour, approximately, on September 29th—eleven shocks were registered, besides the two, or more, mentioned above. At Kapapala, about fifteen miles southwest from the Observatory, on the southeastern flank of Mauna Loa, it was reported that twenty-nine shocks were *felt*, during a similar, but not identical, period. Some were described as sharp, but none was strong.

It was suspected at once that this seismic spasm was an indication that Mauna Loa was about to break into eruption, but no symptom of any such response could be seen from any part of the island. Indeed a visitor to the summit crater in November, a short time before the outbreak actually transpired, did not see any new conditions or unusual phenomena such as might suggest the approach of eruption. This was a Mr. Conant, a resident of the Kona district, who was familiar with the appearance of Mokuaweoweo.

From this time, late in September, shocks kept occurring with unusual frequence up to the date of outbreak, November 25, 1914, when within less than two hours, beginning a little after noon, some twelve or more earthquakes were registered. As mentioned above, this group began at approximately the same time that the Kapapala herdsmen first saw fumes rising above the summit. The first three or four, or more, of these shocks came in quick succession, and just as with the group on September 27th, they maintained continuously for upwards of five minutes an earth vibration of sufficient amplitude to prevent the stopping and re-setting of the power-clock of one of the subordinate seismographs owing to continual making and breaking circuit by the swinging pointer of its sensitive electric starting device. The remaining five or six shocks followed at irregular intervals until about 2:20 p.m., after which no further action was registered.

Like the shocks of September 27th, which we may think of as the beginning of the prelude, these were not perceptible to the senses at the Observatory, though several were of moderately large *instrumental* amplitude; *but unlike the earlier group, so far as can be ascertained, no shock of this lot was perceived by anyone in any part of the island.* Hence, although several earthquakes had been felt in preceding weeks, and an eruption was anticipated by many partly on that account, nevertheless if it had not been for the work of recording seismographs probably it would have been set down—as in May 1880 H. M. Whitney wrote of that eruption—that "this eruption commonced as quietly as moonrise, without any premonitory shakes or noises."

A table (Table I) of the shocks preceding eruption is here included in which is given in Hawaiian Standard Time (meridian of 157° 30′ Long. W. from Greenwich), (*a*) the dates, (*b*) the times of beginning and ending, (*c*) the values of acceleration (controlling intensity) stated in milligals,[1] and (*d*) the distances of origin from the station stated in miles,[2]—all reduced as well as possible from measurement of the seismogram.

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[1] The milligal is the conventional unit of acceleration adopted in the international scheme for seismometric notation. It is a measure of the rate of change of vibratory motion amounting to 1/100 mm. per second per second.

[2] These distances depend upon the accuracy of Zeissig's distance table, *and its applicability to this region.* No local formula for origin-distance can be worked out with the data at hand or now being gathered. However, if the earthquakes of November 25th were epicentral in Mokuaweoweo, as is to be expected, the Zeissig table yields very close values here.

TABLE I

Date 1914	Begins H. S. T.	Ends H. S. T.	Intens. millgls.	Distance miles	Remarks
Sept. 27	10:06 a.m.	10:07+ a.m.			No instrumental record; probably a succession of several shocks, certainly of several maxima. Times for both shocks only approximate.
Sept. 27	10:08 a.m.	10:08+ a.m.			
Sept. 27	1:11:27 p.m.	1:14:29 p.m.	1,500	21	Not felt here.
Sept. 27	1:58:53 p.m.	2:00:03 p.m.	270	21	
Sept. 27	In mid-	afternoon	...	..	Record overscored and undecipherable.
Sept. 27	9:54:23 p.m.	9:56:11 p.m.	250	21—	
Sept. 28	1:38:40 a.m.	1:40:08 a.m.	270	22—	
Sept. 28	1:50:17 a.m.	1:51:21 a.m.	120	20	
Sept. 28	6:40:48 a.m.	6:41:44 a.m.	80	16	
Sept. 28	6:45:30 p.m.	6:47:42 p.m.	380	20	
Sept. 28	8:40:52 p.m.	8:42:44 p.m.	80	Indeterminate	
Sept. 28	10:41:31 p.m.	10:42:01 p.m	500	19.3	
Sept. 28	11:17:49 p.m.	11:18:37 p.m.	350	14.3	
Sept. 29	00:45:15 a.m.	00:46:59 a.m.	940	18.5	
Sept. 29	5:05:31 p.m.	5:07:16 p.m.	120	18.6	
Oct. 2	12:56:54 p.m.	12:58:42 p.m.	280	14.3	
Oct. 2	6:50:31 p.m.	6:50:57 p.m.	160	Indeterminate	
Oct. 3	00:46:57 a.m.	00:49:13 a.m.	440	15	Measure of intensity possibly (?) 2200 milligals. Not felt here.
Oct. 3	7:15± a.m.	7:22± a.m.	...	..	Teleseism—chief phase only.
Oct. 4	5:20:06 a.m.	5:21:06 a.m.	500±	20	
Oct. 6	3:33:21 p.m.	3:34:04 p.m.	310	16.8	
Oct. 7	2:21:26 a.m.	2:22:25 a.m.	56	Indeterminate	
Oct. 10	1:28:40 a.m.	1:29:48 a.m	80	18	
Oct. 10	3:24:17 a.m.	3:26:04 a.m.	180	16.7+	
Oct. 12	3:03:51 a.m.	3:04:46 a.m.	450	9.3	
Oct. 13	11:56:43 p.m.	11:58:15 p.m.	150	Indeterminate	
Oct. 18	3:08:39 p.m.	3:10:39 p.m.	175	"	
Oct. 21	2:50:29 a.m.	2:51:14 a.m.	160	16.2	
Oct. 21	6:49:58 p.m.	6:50:52 p.m.	240	21.0	Measure of intensity possibly (?) 1150 milligals. Not felt here.
Oct. 23	8:29:31 p.m.	8:30:56 p.m.	140	15.0	
Nov. 3	9:03:37 p.m.	9:03:55 p.m.	700	Indeterminate	Origin very near at hand.
Nov. 3	9:03:54 p.m.	9:05:08 p.m.	210	"	Origin very near at hand.
Nov. 3	9:08:22 p.m.	9:08:37 p.m.	95	"	Origin very near at hand.
Nov. 4	3:03:37 a.m.	3:05:09 a.m.	170	15	
Nov. 4	10:35:46 p.m.	10:36:12 p.m.	350	16.8	
Nov. 5	9:00:29 p.m.	9:02:27 p.m.	550	13.7	
Nov. 5	9:04:52 p.m.	9:06:54 p.m.	500	15.5	
Nov. 6	3:06:33 p.m.	3:07:55 p.m.	80	13.7	
Nov. 6	7:24:00 p.m.	7:24:19 p.m.	2200	11.8	This shock was not felt. Exceptionally short *period*.
Nov. 7	6:42:59 a.m.	6:44:26 a.m.	225	32.4	
Nov. 7	10:29:52 a.m.	10:31:00 a.m.	160	29.2	
Nov. 7	11:36:25 a.m.	11:37:41 a.m.	300	20	
Nov. 7	8:33:25 p.m.	8:35:06 p.m.	800	13	
Nov. 8	3:01:27 a.m.	3:01:48 a.m.	70	Indeterminate	
Nov. 8	5:29:20 a.m.	5:29:50 a.m.	120	13	
Nov. 8	7:10:24 a.m.	7:11:10 a.m.	65	29.2	
Nov. 10	10:41:02 a.m	10:42:21 a.m.	95	14.3	
Nov. 10	6:42:33 p.m.	6:43+ p.m.	100	19.3	
Nov. 10	6:43:13 p.m.	6:44:46 p.m.	300	20	
Nov. 10	11:38:43 p.m.	11:40:33 p.m.	600	Indeterminate	This shock, a double-shock, felt gently by writer. Origin nearby.
Nov. 11	8:25:00 a.m.	8:25:39 a.m.	370	13	

Date 1914	Begins H. S. T.	Ends H. S. T.	Intens. millgls.	Distance miles	Remarks
Nov. 13	1:34:42 p.m.	1:36:10 p.m.	240	10.6	
Nov. 13	7:57:36 p.m.	7:59:46 p.m.	1600	15.5	Not reported felt.
Nov. 13	11:20:33 p.m.	11:21:35 p.m.	1000	Indeterminate	Not reported felt.
Nov. 15	12:50:39 p.m.	12:53:27 p.m.	2200	11.7	Felt gently.
Nov. 16	1:23:01 p.m.	1:24:39 p.m.	550	20	
Nov. 17	3:12:29 a.m.	3:13:15 a.m.	1100	Indeterminate	Not felt here.
Nov. 17	7:29:00 a.m.	7:29:15 a.m.	350	13	
Nov. 17	5:44:44 p.m.	5:46:15 p.m.	420	14.3	
Nov. 17	8:30:15 p.m.	8:30:40 p.m.	120	Indeterminate	
Nov. 18	9:40:25 a.m.	9:41:17 a.m.	165	15.5	
Nov. 18	11:15:36 a.m.	11:17:07 a.m.	300	20.3	
Nov. 18	1:43:08 p.m.	1:44:10 p.m.	250	13	
Nov. 18	4:37:30 p.m.	4:38:55 p.m.	190	16.2	
Nov. 19	2:31:45 a.m.	2:32:34 a.m.	190	10.5	Intensity measures possibly (?) 1150 milligals. Not felt here.
Nov. 19	2:44:03 a.m.	2:44:52 a.m.	400	10.6	Intensity measures possibly (?) 2500 milligals. Not felt here.
Nov. 19	4:46:17 p.m.	4:46:45 p.m.	2800	5.3	Exceptionally small *period.* Neither felt nor perceptible.
Nov. 19	7:17:27 p.m.	7:19:01 p.m.	175	13	
Nov. 19	8:06:36 p.m.	8:08:03 p.m.	700	10	
Nov. 19	8:09:08 p.m.	8:09:52 p.m.	700	Indeterminate	
Nov. 20	3:09:41 a.m.	3:10:40 a.m.	65	"	
Nov. 20	3:13:14 a.m.	3:14:13 a.m.	50	"	
Nov. 20	3:44:17 a.m.	3:45:23 a.m.	40	"	
Nov. 20	3:54:44 a.m.	3:55:57 a.m.	180	20	
Nov. 20	6:11:02 a.m.	6:12:36 a.m	270	4.8	
Nov. 20	6:15:13 a.m.	6:16:15 a.m.	65	Indeterminate	
Nov. 20	10:27:13 a.m.	10:27:55 a.m.	65	18.3	
Nov. 20	11:46:08 a.m.	11:46:31 a.m.	300	Indeterminate	
Nov. 20	1:48:41 p.m.	1:49:16 p.m.	450	18.6	
Nov. 20	5:39:01 p.m.	5:39:42 p.m.	500	12.4	
Nov. 21	4:00:17 p.m.	4:01:37 p.m.	1000+	14.3	Not felt here.
Nov. 21	6:03:25 p.m.	6:05:27 p.m.	900	13	Definitely not felt here.
Nov. 22	3:56:40 a.m.	3:57:30 a.m.	70	Indeterminate	
Nov. 22	11:55:56 p.m.	11:56:10 p.m.	450	"	
Nov. 23	6:23:29 a.m.	6:24:58 a.m	200	32	
Nov. 23	10:11:07 p.m.	10:11:20 p.m.	250	Indeterminate	
Nov. 23	11:30:05 p.m.	11:30:50 p.m.	64	"	
Nov. 24	1:32:51 a.m.	2:23± a.m.	...	..	Teleseism.
Nov. 24	9:53:47 a.m.	9:55:05 a.m.	830	10	
Nov. 24	9:57:38 a.m.	9:58:02 a.m	65	Indeterminate	
Nov. 25	12:17:49 p.m.	12:19:30 p.m.	96	20-25 est.	
Nov. 25	12:23:43 p.m.	pen off cyl'der	2400+	21-22	Definitely not felt.
Nov. 25	12:25:50 p.m.	12:27:14 p.m.	300±	20-25 est.	
Nov. 25	12:27:50 p.m.	12:29:26 p.m.	210	20-25 est.	
Nov. 25	12:30:02 p.m.	12:30:50 p.m.	165	20-25 est.	
Nov. 25	12:53:26 p.m.	12:54:47 p.m.	320	20-25 est.	
Nov. 25	12:57:24 p.m.	12:59:09 p.m	65	20-25 est.	
Nov. 25	1:17:18 p.m.	1:18:36 p.m.	65	20-25 est.	
Nov. 25	1:26:57 p.m	1:28:44 p.m.	180	24	
Nov. 25	1:41:19 p.m.	1:42:42 p.m	200	20-25 est.	
Nov. 25	1:49:01 p.m.	1:50:07 p.m.	50	20-25 est.	
Nov. 25	2:13:10 p.m.	2:17:48 p.m.	1080	23	Definitely not felt.

This group of shocks on November 25th announced or accompanied the outbreak of eruption in Mokuaweoweo. There can be little or no doubt that the origins were in and beneath this crater, and there is much reason for thinking them distributed on the great NE-SW rift along which the active fountains were aligned. Between 12:23 p.m. and 12:30 p.m. the motion continued, or frequently recurred, so strong as to keep the recording styluses swinging so far as to sweep off the recording cylinders of all except one of the seismometers.

The summit crater of Mauna Loa is distant almost exactly twenty-two miles in direct line from this Observatory in a direction a trifle N. of W., and it is at an altitude of about 13,675 feet above the sea, while that of the Observatory is only 3,985 feet approximately—a vertical difference of 9,690 feet. Yet so gentle is the slope of the lava dome of Mauna Loa that it *grades down* almost to the very brink of the summit sink-crater of Kilauea where the Observatory stands. However, a deep and extended belt of fissures running in a NE-SW course passes about one mile west of the Observatory partially severing the great mountain from Kilauea. This, of course, tends to quench wave motion in the rock originating to the west of the fissure zone, particularly when it emanates from nearby, shallow origins.

With reservations [3] it is to be noted that an earthquake in which the acceleration amounts to 1,000 milligals is considered to be just perceptible to human beings of normal sensitiveness—but several shocks of this series considerably exceeded this magnitude here and definitely were not felt.

Though it is a fact to be expected, it is nevertheless worthy of note that none of these local shocks were registered by the very sensitive, photo registering, Milne seismograph installed at the Magnetic Station of the U. S. C. & G. S. at Ewa, near Honolulu, more than a hundred miles from Mokuaweoweo. On the other hand some thirty-one teleseismic disturbances were registered there during the interval covered by this table, only two of which were strong enough to operate the mechanically registering instruments installed here upon a foundation of badly fissured basalt.

Following the crisis of volcanic outbreak there was no sequence of shocks such as to suggest a cycle of aftershocks; nor, on the other hand, was there a complete cessation of seismic activity. Rather, local earthquakes continued to occur as usual in normal times, in respect to number, to magnitude, and to special characteristics as well. The following table (Table II) completes the list to the end of 1914.

Therefore we see, despite the title of this paper and the actuality of the seismic prelude here shown, ***the present eruption of Mauna Loa, like many others in previous years, said to have commenced quietly, is remarkable for the relative absence of marked seismic action.*** Whatever view be taken as to the nature of volcanic action, the sequence of

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[3] See "Concerning the perceptibility of weak earthquakes, etc.," by the present writer in *Bulletin Seismological Society America*, **4**, 1, March 1914.

TABLE II

Date 1914	Begins H. S. T.	Ends H. S. T.	Intens. millgls.	Distance miles	Remarks
Nov. 26	11:16:08 p.m.	11:17:29 p.m.	110	23	
Nov. 27	6:48:05 p.m.	6:49:05 p.m	320	25	
Dec. 9	10:55:01 a.m.	10:55:55 a.m.	110	32	
Dec. 10	8:21:36 a.m.	8:22:20 a.m.	110	20	Shock not felt here.
Dec. 13	7:40:13 p.m.	7:41:33 p.m.	1000+	20—	Shock not felt here.
Dec. 17	7:05:51 p.m	7:06:53 p.m.	1550±	12.4	
Dec. 18	7:52:40 a.m.	7:54:13 a.m.	70	Indeterminate	
Dec. 19	4:42:38 p.m.	4:44:12 p.m.	270	20	
Dec. 19	9:05:58 p.m.	9:06:58 p.m.	80	Indeterminate	
Dec. 22	8:37:45 p.m.	8:38:04 p.m.	900	10.5	
Dec. 22	11:03:01 p.m.	11:03:58 p.m.	175	29	
Dec. 23	3:47:32 p.m.	3:48:43 p.m.	135	18	
Dec. 27	8:47:47 a.m.	8:49:12 p.m.	220	29	
Dec. 28	00:49:07 a.m.	00:50:12 a.m.	110	29	
Dec. 28	5:09:13 a.m.	5:09:43 a.m.	700	Indeterminate	

shocks in the present instance appears to mark a volcanic, as distinct from a seismic crisis.

Consequently the phenomena of the present outbreak stand in pronounced contrast with the circumstances attending the eruptions of 1868 and 1887, and to a lesser extent that of 1907. But, like the present, the great majority of the eruptions of Mauna Loa have begun without conspicuous seismic activity, as determined by ordinary observation. Bearing upon this point the following resumé is of interest:

RECORDED ERUPTIONS OF MAUNA LOA

1832, June 20—Action at or near the summit, recorded as flows, but not visited.
Possibly only action in crater.
"Earthquakes frequent on Hawaii during summer."

1843, Jan. 9—Action at summit for a week, then flow down north slope toward Mauna Kea, running for about six weeks.
No mention of earthquakes.

1849, May —Action at summit for three weeks.
No flow recorded.
No mention of earthquakes.

1851, Aug. 8—Flow down W. slope, of small size and short duration.
Detonations heard—only record of this kind.
No earthquakes recorded.

1852, Feb. 17—Flow down N.E. slope, for less than one month.
No earthquakes recorded.

1855, Aug. 11—Flow down N.E. slope, a great flow running for sixteen months.
No earthquakes noticed, a specific statement on record.

1859, Jan. 23—Flow down N.W. slope, a great flow running for many weeks.
No earthquakes at commencement, a specific statement on record.

1865-66, Dec. 30—Action at summit, varying in apparent intensity, for four months.
No flow.
No earthquakes reported, a specific statement on record.

1868, Mar.-Apr.—Action at summit, with flows near summit, for a few days, then flow down S.W. slope into sea, vigorous but of short duration.
Thousands of earthquakes, many strong; at least one of MODERATE WORLD-SHAKING POWER.

As the present writer has recently pointed out, it is not unreasonable to regard this as a grand, or major, seismic crisis incidentally attended by eruptive action.

1870, Jan. 1—Slight action at summit for two weeks.
No flow.
Slight earthquakes frequent.

1872, Aug. 10—Action at summit for a few weeks.
No flow.
No earthquakes.

1873, Jan. 6—Action at summit, brilliant; short duration, not recorded.
No flow.
No earthquakes recorded.

1873-74, Apr. 20—Action at summit continuous for more than 18 months.
No flow.
No significant earthquakes; a few feeble shocks during the entire long interval.

1875, Jan. —Action at summit for one month.
No flow.
No earthquakes recorded.

1875, Aug. 11—Action at summit for one week.
No flow.
No earthquakes recorded.

1876, Feb. 13—Action at summit; short duration, not recorded.
No flow.
No earthquakes recorded.

1877, Feb. 14—Action at summit for ten days, then
Feb. 24 probable submarine outflow off west coast.
Submarine earthquake felt near outbreak, but no shock felt on land nearby.
Sea-wave experienced along beach line.

1880, May 1—Action at summit, lofty magma fountains; short duration.
No flow.
No earthquakes noticed, a specific statement on record.

1880-81, Nov. 5—Flow down N.E. slope, a great flow running for nine months.
No "violent demonstrations or earthquake."

1887, Jan. 16—Flow down S.W. slope.
Probably thousands of moderately strong local earthquakes, but none of world-shaking energy, beginning in December 1886.
Very reasonably, we may consider this a minor seismic crisis, attended by eruptive action.
1896, Apr. 21—Action at summit, of unrecorded duration.
No flow.
No earthquakes recorded.
1899, July 1—Action at summit seen vaguely.
4—Action at summit seen with certainty.
5—Flow down N.E. slope for three weeks.
No earthquakes recorded at time of outbreak, but both before and after several were recorded.
1903, Oct. 6—Action at summit for two months.
No flow.
No earthquakes recorded.
1907, Jan. 10—Action at summit, doubtful.
Flow down S.W. slope for about two weeks.
Several slight earthquakes, but felt in a few places only.
1914, Nov. 25—Action at summit still in progress at date of writing.
No flow as yet.
Seismic prelude instrumentally discovered, otherwise seismic action as in many previous instances.

Thus, study of these eruptions appears to justify the presumption that in all or most instances continuous seismic registration with such mechanisms as are available at the present day would have established the occurrence of weak seismic preludes, as in this latest event.

With regard to the Hawaiian volcanoes, at least, there appear to be good reasons for anticipating increase in activity, or increased eruptive tension—whatever the cause—at and around the time of solstice, and on account of lag for a little time thereafter. Actual date of outbreak, of course, is less definitely, though all the same suggestively, related to this astronomical crisis. With this idea, and that of the seismic prelude also, in mind it will be well to examine the list of shocks which occurred between the first of April, 1914, and the enforced cessation of registration in August. These are listed in Table III. The writer does not undertake to derive any conclusion from the tabulation—merely to present the facts for examination.

TABLE III

Date 1914	Begins H. S. T.	Ends H. S. T.	Intens. millgls.	Distance miles	Remarks
April 3	10:30:17 p.m.	10:31:32 p.m.	1000±	12	Shock not felt here.
April 4	8:14:16 a.m.	8:15:50 a.m.	190	12	
April 4	7:06:21 p.m.	7:07:37 p.m.	1000±	13.7	Shock not felt here.
April 6	3:20:35 p.m.	3:21:22 p.m.	350	13	
April 9	3:13:56 p.m.	3:14:30 p.m.	900	12	
April 12	11:27:36 p.m.	11:28:24 p.m.	600	11.2	
April 13	00:48:23 a.m.	00:49:01 a.m.	700	14.3	
April 13	4:15:37 a.m.	4:17:08 a.m.	800	20±	
April 13	1:01:58 p.m.	1:03:03 p.m.	400	10.6	
April 13	9:28:37 p.m.	9:31:31 p.m.	1450	20±	Felt, barely.
April 15	1:57:28 a.m.	1:58:52 a.m.	1600	13.7	Not reported felt here.
April 21	7:24:13 a.m.	7:25:08 a.m.	700	12.4	
April 29	2:56:10 p.m.	3:15± p.m.	6000+	20	Felt, feeble, II R-F.
April 29	2:59:36 p.m.	2:59:54? p.m.	4500	20(?)	Felt (?), 2d max. of foregoing shock.
April 29	6:37:25 p.m.	6:38:15 p.m.	56	Indeterminate	
April 30	3:18:42 a.m.	3:19:46 a.m.	650	"	
April 30	11:28:30 a.m.	11:30 a.m.	700	18.6	
May 12	11:12:30 a.m.	11:13 a.m.	1000±	Indeterminate	Shock not felt here.
May 12	9:10:14 p.m.	9:12:34 p.m.	900±	15.5	But felt very slightly, I RF.
May 12	9:59:36 p.m.	10:00:13 p.m.	450	12.4	
May 13	3:41:54 p.m.	3:42:31 p.m.	2500	10	Shock not reported felt.
May 22	4:38:26 a.m.	4:39:25 a.m.	350	13	
May 23	7:52:24 p.m.	7:54:01 p.m.	300	25	
May 24	5:27:35 a.m.	5:28:59 a.m.	500	13	
May 26	2:01:49 a.m.	2:02:24 a.m.	400	13	
May 27	3:30:18 p.m.	3:31:58 p.m.	140	30	
May 28	9:17:27 a.m.	9:18:57 a.m.	240	9.3	
May 29	8:23:26 p.m.	8:24:22 p.m.	800	10	
June 1	6:29:28 a.m.	6:36:05 a.m.	...	Nearby	Felt, III R-F, beyond range of seismometers.
June 1	12:16:03 p.m.	12:16:51 p.m.	600	6.9	
June 2	5:15:02 a.m.	5:15:40 a.m.	65	Indeterminate	
June 2	5:25:37 p.m.	5:26:28 p.m.	650	7.5	
June 2	6:24:45 p.m.	6:25:22 p.m.	650	7.5	
June 5	4:54:14 p.m.	4:55:35 p.m.	320	15	
June 11	10:06:49 p.m.	10:08:37 p.m.	110	27	
June 15	1:54:50 p.m.	1:55:10 p.m.	200	Indeterminate	
June 17	8:43:03 a.m.	8:44± a.m.	65	12	
June 19	11:20:20 a.m.	11:21:29 a.m.	1000±	19.4	Shock not felt here.
June 20	12:47:30 a.m.	12:48:18 a.m.	500	11.7	
June 20	1:46:00 p.m.	1:48:38 p.m.	1900	10	Not reported felt here.
June 25	9:29:08 a.m.	9:32:25 a.m.	1200	20	Not reported felt here.
July 1	2:28:01 a.m.	2:28:55 a.m.	48	20	
July 1	5:37:09 p.m.	5:38:30 p.m.	500	Indeterminate	
July 2	5:30:13 p.m.	5:31:13 p.m.	500	"	
July 5	2:42:15 p.m.	2:44:11 p.m.	190	12.4	
July 5	3:16:01 p.m.	3:21.6- p.m.	3300	12.4	Not reported felt, but probably really perceptible.
July 5	3:51:43 p.m.	3:53:05 p.m.	1200	12.2	Not reported felt.
July 5	4:36:00 p.m.	4:37:27 p.m.	270	13	
July 5	6:42:25 p.m.	6:44:04 p.m.	110	Indeterminate	

Date 1914	Begins H. S. T.	Ends H. S. T.	Intens. millgls.	Distance miles	Remarks
July 5	7:18:14 p.m.	7:20:58 p.m.	6200±	13	Not felt here, but felt sharply two miles to N.E.
July 5	7:25:42 p.m.	7:27:38 p.m.	535	13	
July 5	7:30:02 p.m.	7:31:50 p.m.	88	Indeterminate	
July 5	8:03:49 p.m.	8:04:16 p.m	130	"	
July 5	9:37:06 p.m.	9:39:17 p.m.	80	20	
July 6	1:39:03 a.m	1:40:37 a.m.	940	13.7	
July 6	11:05:19 a.m.	11:07:07 a.m.	70	13	
July 6	12:45:34 p.m.	12:47:18 p.m.	225	20	
July 6	1:23:15 p.m.	1:24:56 p.m.	65	13	
July 8	11:47:29 a.m.	11:48.5 a.m.	60	Indeterminate	
July 8	7:21:45 p.m.	7:23:28 p.m.	80	13	
July 9	9:36:43 a.m.	9:38:25 a.m.	950	6.9	
July 9	1:31:57 p.m	1:33:11 p.m.	75	6.9	
July 9	1:38:04 p.m.	1:39:46 p.m.	190	13	
July 9	2:18:19 p.m.	2:19:02 p.m.	300	Indeterminate	
July 9	5:24:51 p.m.	5:25:29 p.m.	300	10	
July 14	9:19:23 p.m.	9:20:51 p.m.	160	13	
July 16	6:17:07 a.m.	6:17:50 a.m.	90	Indeterminate	
July 17	00:11:20 a.m.	00:13:28 a.m.	110	19.3	
July 17	8:39:55 p.m.	8:41:23 p.m.	55	Indeterminate	
July 19	8:50:47 a.m.	8:51:22 a.m	1100	11.8	Shock not felt here.
July 20	4:03:20 a.m.	4:06:33 a.m.	2500	20	Felt, II R-F.
July 22	9:09:24 a.m.	9:10:08 a.m	400	Indeterminate	
July 22	8:36:51 p.m.	8:37:36 p.m	550	13	
July 23	3:41:59 a.m.	3:43:33 a.m.	140	6.9	
July 29	10:45:39 p.m.	10:46:15 p.m.	100	26	
Aug. 6	1:24:42 a.m.	1:26:26 a.m.	165	26	
Aug. 6	7:15:03 a.m.	7:15:51 a.m.	120	19.3	
Aug. 6	8:19:24 a.m.	8:20:12 a.m.	1000±	12.4	Shock not felt here.
Aug. 10	2:30:00 a.m.	2:30:32 a.m.	750	Indeterminate	
Aug. 10	4:00:43 p.m.	4:01:59 p.m.	400	13	
Aug. 12	7:20:41 a.m.	7:21:29 a.m.	160	19.3	

No more shocks were recorded before the temporary cessation of registration, which was resumed on September 27th.

Finally, attention should be drawn to the fact that for some days preceding and following the summit outbreak the seismographs—all horizontal pendulums—were in continual response to a surface tilt of uncommon amount to the E. and N. The seismograph cellar is east and a trifle south of the center of the summit-crater of Mauna Loa, distant 22 miles, and it is very close to the brink of the great caldera of Kilauea at its northeast margin. Whether this association of unusual tilt and volcanic outbreak is casual or coincidental cannot at the present stage be determined. Such tilting has occurred here at other times.

In view of all the above, in the writer's judgment, the reality of the seismic prelude is considered to be established; but nothing appears in the sequence of events which would have justified confident, or definite, *prediction* of outbreak, even though a lively anticipation of eruption was created.

Hawaiian Volcano Observatory,
December 31, 1914.

SEISMOLOGICAL NOTES

Oakland, California, November 8, 1914.—Mr. Charles Burckhalter, of the Chabot Observatory, observed the earthquake of November 8th at 6:31:31 p.m. The shock was felt by many people, and was accompanied by a faint sound, while the total duration was about six seconds and the intensity IV, Rossi-Forel scale.

Kingston, Jamaica, November 15, 1914.—Mr. J. F. Brennan of the Public Works Office at Kingston has kindly sent us a brief account of two earthquakes with seismographic records. The first earthquake occurred November 15, at 12:47 a.m., the shock lasting about five seconds, and having a nearly north-south direction. The horizontal movement recorded by the seismograph was 0.040 inch.

The second shock was felt on December 24th at 10:45 p.m., lasting about ten seconds. The direction was southeast-northwest, while the horizontal movement recorded by the seismograph was 0.090 inch.

Minor shocks occurred on November 15th at 8:42 a.m. with a recorded horizontal movement of 0.002 inch, and on December 5th at 10:00 a.m. with a horizontal movement of 0.008 inch.

Coracora, Peru, December 6, 1914.—Coracora, a small town about three hundred miles southeast of Lima in the department of Ayacucho, was almost destroyed by an earthquake.

Santa Cruz Mountains and San Francisco Bay region, California, December 28, 1914.—At about 2:45 a.m. an earthquake was felt throughout the Santa Cruz mountains, in the northern part of the Santa Lucia mountains, and in the San Francisco Bay region. A summary of the reports sent to the Society is given below:—

Aqua, Milbrae, San Mateo county.—Spring Valley Water Company: time, 2:43 a.m. The shock, which rocked the building east and west, lasted two seconds, and was generally felt, but caused no alarm. No noise accompanied the shock, the intensity being IV, Rossi-Forel scale.

Boulder Creek.—Professor E. D. Adams reports that the shock was more severe than the one of November 8th. The timbers in the Big Basin Hotel creaked.

Felton, Santa Cruz county.—The earthquake here was harder than the one on November 8th.

Monterey.—C. H. Beal: Earthquake of intensity between III and IV, Rossi-Forel scale, felt at about 2:45 a.m. Buildings swayed.

Niles, Alameda county.—Spring Valley Water Company: time, 2:43 a.m.; duration, two seconds; very few people felt the shock, and no noise was heard; intensity, III, Rossi-Forel scale.

Oakland.—Charles Burckhalter: time, 2:43:58 a.m. There were about ten wave-like shocks, lasting six seconds. Only a few people felt the earthquake, and the intensity was between II and III, Rossi-Forel scale.

Palo Alto.—D. M. Folsom: time, about 2:45 a.m. The earthquake was described as one single jar lasting from one to three seconds and having an intensity between II and III, Rossi-Forel scale.

San Andreas Lake, two miles south of Milbrae.—Spring Valley Water Company: time, 2:45 a.m. The shock swayed the house slightly and was generally felt, but was accompanied by no noise. The intensity was given as V, Rossi-Forel scale, and the duration from four to five seconds.

San Jose.—Harold A. Chapin: A sharp earthquake, lasting four or five seconds, was felt at 2:43 a.m. with the movement in a north-south direction.

Santa Lucia mountains, twenty miles southeast of Monterey.—C. H. Beal: A gentle rocking motion lasting two or three seconds was felt at 2:44 a.m. The house swayed slightly, and an intensity of III, Rossi-Forel scale, was estimated.

Stanford University.—J. C. Branner: Awakened by an earthquake at 2:43 a.m., lasting about four or five seconds. Intensity III.

W. F. Durand: time, 2:42 a.m. A distinct swaying motion was felt while lying in bed on the second story of a frame house. The shock lasted two seconds or less and awakened Professor Durand. The house creaked slightly, and the intensity of the shock was about II.

S. D. Townley: Earthquake at 2:44 a.m.; intensity III, Rossi-Forel scale.

Summerville, Oregon, January 18, 1915.—A light earthquake was felt at Summerville, Oregon. The shock is said to have been felt over an area of forty square miles.

Panama, January 24, 1915.—Three earthquake shocks are reported on the Isthmus of Panama on the 24th, 25th, and 26th of January, 1915. No damage was reported.

London, January 27, 1915.—The following is quoted from the Los Angeles *Tribune* of January 27th: The West Bromwich observatory registered a severe earthquake today. The observatory officials said the shock probably centered in Greece or Turkey.

Rome, February 2, 1915.—It is reported from Rome that earth disturbances of a minor nature continue at Avezzano, the scene of the disaster of January 13th, the most important feature being the lower level of Lake Paterno by sixteen feet.

Yorkshire, England, February 2, 1915.—Shocks were felt in the coal districts in Yorkshire, England, during the night of February 2, 1915. The shaking down of the roofs of the mines closed some of the openings.

Brazil, February 2, 1915.—From our fellow member Dr. Euzebio de Oliveira of the Serviço Geologico do Brazil, we learn that there was a light earthquake shock at Conceição de Itanhaem, state of S. Paulo, Brazil, in the early morning of February 2d. Windows and lamps were broken and dishes rattled. Dr. Oliveira judges from the newspaper reports that the earthquake had an intensity of IV, R-F. scale. The town of Conceição de Itanhaem is on the coast, fifty kilometers southwest of the city of Santos and near the base of the Serra dos Itatins, which has an elevation of more than a thousand meters. Fifty kilometers to the northwest of the town is the crest of the great Serra do Mar, a granite range, with a steep escarpment facing the ocean and having an altitude of a thousand to twelve hundred meters.

Manua, Samoa, February 10, 1915.—On February 10 (?), 1915, a hurricane on the Manua islands of the Samoan group was accompanied by an earthquake.

Merrimac valley, February 20, 1915.—On February 20th, an earthquake was felt between 9:20 and 10 p.m. along the Merrimac river in the state of Massachusetts. The shock was reported from Amesbury, Lawrence, Andover, Haverhill, and adjacent towns. No damage was done.

Iceland, February 20, 1915.—On the 20th and 21st of February several serious shocks were felt at Reykjabik, Iceland, and in the surrounding region.

Lassen Peak, California.—The eruptions at Lassen Peak during the last five months have been of the same nature as those previous to August 24, 1914, an account of which was given by J. S. Diller in the September BULLETIN.

There have been eighty-four eruptions since the first one on May 30, 1914, or an average of one eruption every 3.5 days for the total. From May 30, 1914, to August 23 there was one eruption every 2.7 days, and from August 24, 1914, to March 22, 1915, one eruption every 4 days. From these averages it seems that the volcano is becoming less active.

The chronology of the activity at Lassen Peak is summarized from newspaper reports as follows:

January 23, 1915.—Seventy-fourth eruption at 9:00 a.m., lasting two hours. A subterranean rumble is said to have been heard twenty-two miles distant an hour before the eruption. The smoke rose to a height of several thousand feet, drifting to the northeast and scattering ashes over Macomber Flat and into Hat Creek and Lost Creek valleys, a distance of over twenty miles. Earthquake shocks shook the region at intervals for twenty minutes preceding the eruption.

February 12, 1915.—Steam and smoke with occasional terrific outbursts are said to have issued from the crater during the day.

February 21, 1915.—A severe earthquake is said to have been felt on the evening of February 21st in Twin valley, thirty miles east of Redding and twenty miles north of Mount Lassen.

March 1, 1915.—Reported that a stream of mud was forced from the crater and ran down the western side.

March 11, 1915.—Eightieth eruption was observed. For an hour the crater emitted dense black smoke and ashes.

March 19, 1915.—Eighty-first eruption. A cloud of white smoke, which apparently came from a vent near the base of the north side of the peak in the region about Manzanita Lake, was observed at 7:00 a.m., and a short time later a cloud of black smoke rose apparently from the region near Bumpass' Hell, about three miles southeast of the crater. At 9:00 a.m. steam began to issue from the main crater, which until then had shown no sign of activity.

March 20, 1915.—Eighty-second eruption. A large column of smoke rose straight through the still air to a high altitude.

March 21, 1915.—Eighty-third eruption. During the morning smoke poured from a vent near the timber-line in the region about Manzanita Lake, and at 3:00 p.m. clouds of black smoke issued from the main crater.

March 22, 1915.—Eighty-fourth eruption. For the fourth consecutive morning Lassen Peak erupted, most of the smoke issuing from the main crater.

REVIEWS

THE REGISTRATION OF EARTHQUAKES AT THE BERKELEY STATION AND AT THE LICK OBSERVATORY STATION FROM APRIL 1, 1914, TO SEPTEMBER 30, 1914. By E. F. Davis. *University of California Publications, Bulletin of the Seismographic Stations,* No. 8, pp. 155-168.

During the period covered by this report twenty-four earthquakes were recorded by the Berkeley Station, and thirty-eight by the Lick Observatory Station. The greater part of the earthquakes recorded at the Lick Observatory Station were local shocks originating within short distances from the Lick Observatory.

A brief discussion is given of the earthquake of April 24, 1914. This earthquake gave excellent records both at Berkeley and at the Lick Observatory, the amplitudes being unusually large at both stations. The shock was felt at numerous places in California and Nevada. Complete information as to the distribution of intensity was not obtained, but it is known that this earthquake was felt at many places along the Sierra front between Randsburg and Susanville. It was felt as far west as Stockton and Sacramento, and as far east as Winnemucca. At Sacramento the intensity was great enough to cause a few people to run into the streets. In spite of the large area affected by this earthquake, it was not reported as being exceptionally severe at any place. The suggestion is made that this earthquake was one whose depth of origin was greater than is usual for earthquakes in this region.

Among the earthquakes of local interest which were recorded at the Berkeley Station are the Tonopah earthquake of April 6, 1914, and an earthquake originating near Oxnard, California, on June 16, 1914.

KATALOG DER IM JAHRE 1907 REGISTRIERTEN SEISMICHEN STÖRUNGEN, VON SIEGMUND SZIERTES, STRASSBURG 1912. *Publications du bureau central l'association internationale de sismologie.* Serie B. Catalogues.

In this catalog are gathered together and arranged in chronological order, for the first time, the microseismic data from all the seismological laboratories of the world. From a few up to a score of earthquake disturbances are recorded for practically every day of the year. The data are derived from the reports of 150 stations. In every case the date, name of station, and type of seismograph are given. In addition to the above data the time of arrival at the station in question of the first and second preliminary tremors and the principal waves is given whenever these are known. Whenever the same seismic disturbance is reported from more than one station this fact is indicated by not repeating the date in the date column. If other earthquakes occur on the same day, as is usually the case, the date is repeated.

In a separate pamphlet entitled "Registrierungen der besser ausgepragten seismischen Störungen des Jahres 1907" are published much fuller data in regard to what may be called world-shaking earthquakes. There are 96 of these earthquakes, which are only mentioned in the "Katalog," leaving full data for the "Registrierungen." These 96 earthquakes are reported from many stations, often as many as 50 giving data for the same earthquake. Earthquakes No. 21 and No. 79, which both occurred on the Pacific coast of Mexico, were registered by the seismographs of 82 and 59 stations respectively.

The epicenters of each of these earthquakes has been determined, and the distance of the epicenter from each of the stations reporting it is given both in degrees and minutes and in kilometers. The time of arrival of the principal phases at each of the stations is given in the "Registrierungen," the same as the minor earthquakes are recorded in the "Katalog."

The large amount of data here collected and systematized will be found invaluable by seismologists. As an example, we may make use of some of the data to determine the time required for the first preliminary tremor to be transmitted directly through the earth to the antipodes. Of the 96 major earthquakes, 15 produced records at stations whose distances from their epicenters were 160° or more. In all these cases the most distant station obtaining records was not very far from the antipodes of the epicenter. In many cases the records of the first preliminary tremor were not obtained or the time of arrival was uncertain. Selecting 6 earthquakes for which the data seemed satisfactory, the results tabulated were obtained.

In order to determine the time of transmission along the chord it was necessary to determine the time of occurrence of the earthquake. This was done by making use of the known velocity of the first pre-

No. of Earthquake	Distance from Epicenter	Time of Transmission along Chord	Corrected Time for Diameter
21	157° 55′	19m 40s	20m 4s
38	160 45	19 53	20 10
41	171 14	21 5	21 9
50	164 02	20 14	20 26
83	162 13	19 24	19 38
95	165 48	20 12	20 24

liminary tremor and the time of arrival at the nearest station where a record was obtained. The time of transmission along a diameter was then obtained on the assumption that the velocity along a diameter is the same as along a chord which is close to the diameter.

F. J. Rogers.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Denver, Colorado, U. S. A., Jesuit Seismological Service.—Reports nos. 6-12, June 1 to December 31, 1914, and no. 1, January 1 to January 31, 1915.

Georgetown University, Washington, D. C.—Special Seismographical Bulletin for January 13, 1915, and report no. 1, January 1 to February 1, 1915.

Harvard University, Cambridge, Mass.—Records of the Seismographic Station, nos. 17-19, November 1 to December 31, 1914; and special bulletins for January 13, 1915, and for February 19 and 20, 1915.

Ottawa, Canada, Earthquake Station, Dominion Astronomical Observatory.—Reports nos. 21 and 22, November 30 to December 31, 1914, and nos. 1 and 2, January 1 to February 28, 1915.

ASIA

Zi-Ka-Wei, China.—Bulletin Sismique, nos. 9, 11, 11 bis and 12, July 3 to October 21, 1914.

EUROPE

Stonyhurst College Observatory.—Earthquake records by Milne seismograph, November 4 to December 27, 1914.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological bulletins of the Observatory, nos. 25-28, August 1 to September 30, 1914.

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS OF THE SEISMOLOGICAL SOCIETY OF AMERICA.

January 20, 1915.

The meeting was called to order at 3 p.m. by Vice-President Tolman, in Room 66, Stanford University. Directors Branner, Tolman, and Townley were present.

The minutes of the meeting of the Board held on April 22, 1914, were read and approved.

Eight new members, whose names are subjoined hereto, were recommended and duly elected to membership in the Society. Four institutions were placed upon the list of subscribers to the Bulletin.

The Secretary reported the death of Mr. W. R. Eckart, Mr. Beach Thompson, and Professor N. H. Winchell, members of the Society. The resignation of eleven members and two subscribers, and the dropping of seven members for the non-payment of dues, was reported.

The Secretary reported also the resignation of Dr. H. W. Fairbanks. Professor W. F. Durand was appointed a Director of the Society to fill out the unexpired term of Mr. Fairbanks.

A nominating committee and a board of election were appointed as follows:

Nominating Committee	Board of Election
R. S. Holway (chairman)	D. S. Richardson (chairman)
B. A. Baird	E. F. Davis
H. L. Haehl	J. A. Taff
W. G. Reed	H. W. Turner
C. F. Tolman	L. Wagoner

The matter of holding a meeting of the Society next August in conjunction with other scientific societies was discussed, and a committee of three, consisting of R. S. Holway, C. F. Tolman, and S. D. Townley was appointed to arrange a program for the meeting.

S. D. Townley, Secretary.

MEMBERS ELECTED JANUARY 20, 1915.

Oscar A. Benson: Rock Island, Ill.
Frederick E. Brasch: Stanford University, Cal.
Richard Ellsworth Call: New York, N. Y.
Carlos T. Lisson: Lima, Peru.
Edward J. Nolan: Philadelphia, Pa.
Andrew H. Palmer: San Francisco, Cal.
W. C. Repetti, S. J.: Fordham University, New York, N. Y.
Mathias de Oliveira Roxo: Rio de Janeiro, Brazil.

NEW SUBSCRIBERS

Denkmann Memorial Library of the Augustana College and Theological Seminary: Rock Island, Ill.
Library of Bureau of Mines: Toronto, Canada.
Library of Ohio Wesleyan University: Delaware, Ohio.
Library of Princeton University: Princeton, New Jersey.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock**: felt by several persons at rest: strong enough for the direction or duration to be appreciable.

IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

VI. **Fairly strong shock**: general awakening of those asleep, general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very strong shock**: fall of chimneys, cracks in walls of buildings.

IX. **Extremely strong shock**: partial or total destruction of some buildings.

X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

The Bulletin of the
Seismological Society of America

VOL. V JUNE 1915 NO. 2

THE INAUGURATION OF SEISMOLOGICAL WORK IN THE UNITED STATES WEATHER BUREAU

By Andrew H. Palmer

By virtue of authority granted by Congress, seismological work is now being conducted by the United States Weather Bureau. The inauguration of the work has progressed slowly since July 1, 1914, when the authority became effective. As no specific appropriation for the work was solicited from Congress, it was provided that it should be done with funds appropriated for general meteorological purposes. For this reason the inauguration and the extension of the service will necessarily be slow. The Weather Bureau has been selected to carry on this work, not because of any inherent relation between meteorology and seismology, but rather because it is, of the various Federal scientific institutions, the one best fitted for this duty. With approximately two hundred regular and permanent stations manned by trained observers accustomed to the care of delicate instruments, it also has the cooperation of more than four thousand volunteer observers. A wide distribution of competent observers is necessary for successful work both in meteorology and in seismology. The Chief of the Weather Bureau, Professor Charles F. Marvin, has placed the work under the supervision of Professor William J. Humphreys.

Non-Instrumental Observations

The seismological work will consist, at the beginning, of a systematic collection of non-instrumental observations. Particular attention will be paid to recognized seismic districts, such as the following: (1) the Pacific Coast, (2) the Rocky Mountains, (3) that part of the Mississippi Valley in the vicinity of Missouri, (4) certain parts of New York State and New England, and (5) possibly the region in the vicinity of Charleston, S. C. The two hundred regular Weather Bureau stations will report earthquakes directly to the Central Office in Washington, D. C. Cooperative observers have been invited voluntarily to assist in the work by reporting, on cards that are furnished for that purpose, the date, etc., of each earthquake noted. Though the time required of each cooperative observer for this purpose is obviously but a few minutes in a whole year, the collected results will be permanent and extremely valuable, absolutely essential to the construction of seismic maps, and exceedingly helpful in the explanation of many obscure earthquake phenomena. The invitation to assist has met with a generous response, and Section Directors, through whom this phase of the work will be conducted, have already received assurances of cooperation from large numbers of their correspondents. On the opposite page is shown a copy of the cards with which the cooperative observers are supplied for the purpose of reporting earthquakes.

Instrumental Observations

In one sense seismological work is being resumed, rather than inaugurated, in the Weather Bureau. For a number of years a Marvin (vertical pendulum) seismograph was in operation in the basement of the Central Office in Washington. This instrument was restored to operation October 12, 1914. A pair of Bosch 25-kilogram horizontal pendulums has recently been installed at Northfield, Vermont. Moreover, the Bureau has the kind assistance and cooperation of practically all other seismic observatories in North America, from Panama to Alaska.

Because the present disturbed conditions in Europe render it almost impossible to secure seismological instruments of foreign manufacture, it has been decided to design a special type of seismograph to be manufactured in this country and which, it is hoped, will prove peculiarly appropriate for use at Weather Bureau stations. The essential characteristics of this seismograph may be briefly gathered from the following category of features set down originally for guidance in designing the instrument:

(1) To register horizontal motion.

(2) Mechanical registration (smoked paper).

(3) Separate pendulums for the two components, mounted on a single base plate and arranged with axes of oscillation accurately at right angles to each other, thereby securing the most exact resolution of the earthquake vibrations into rectangular components.

(4) Two components recorded on a single drum.

(5) Pendulum of inverted type rendered stable by the action of flat, highly tempered steel springs, supplemented by additional spring

U.S. DEPARTMENT OF AGRICULTURE, WEATHER BUREAU (SEISMOLOGY)

Cross out words and parts not applicable, and fill in all remaining spaces.
Use other side, if desired, for additional description and information.

Date of earthquake: ...., 19.......
Time of beginning (use railroad time): Hour............ min.,.............., a.m., p.m.
Location of observer:
On mountain, hill, plain, in valley. Outdoors, indoors, 1st, 2d, 3d, ...floor.
State....................................., town.......................................
Street.., No.................
If in country, distance...................., direction...............
from......................................(nearest P. O. or town).
What doing: Lying down, sitting, standing, walking,..
Onset of shocks: Abrupt, rapid, gradual.
Nature of shocks: Bumping, rocking, trembling, twisting..................................
Intensity (give number, see scale on other side): ....
Number of shocks during earthquake: ....
Duration of each:..
Direction of vibration: N.-S.; NE.-SW.; E.-W.; SE.-NW.
Sounds: No, yes. Before, with, after shocks. Faint, loud, rumbling, rattling.
Felt by: One, several, many.
Name of observer:..
Address of observer:..

(Back of Card)

REMARKS.

EARTHQUAKE INTENSITIES. (Adapted Rossi-Forel.)

1. Felt only by an experienced observer, very faint.
2. Felt by a few persons at rest, faint.
3. Direction or duration appreciable, weak.
4. Felt by persons walking. Doors, etc., moved.
5. Felt by nearly everyone. Furniture moved.
6. Bells rung, pendulum clocks stopped. Alarm.
7. Fall of plaster, slight damage. Scare.
8. Fall of chimneys, walls cracked. Fright.
9. Some houses partly or wholly wrecked. Terror.
10. Buildings ruined, ground cracked. Panic.

reactions, capable of adjustment both for the purpose of securing stability of the pendulum and for adjusting the period of oscillation.

(6) Period of pendulum to be 15 seconds or more if practicable, but not less than 10 seconds, and subject to adjustment.

(7) Magnification 85 to 100 or as much less as may be desirable for registration of strong motion.

(8) When undamped, amplitude of oscillations of pendulum should not diminish more than ten per cent of itself when writing record.

(9) Air or electro-magnetic damping of adequate amount subject to adjustment to be applied.

(10) Time to be marked on record sheet each minute by positive motion of recording pen.

(11) The axes of oscillation of the pendulum to be fixed exactly at right angles by virtue of the mechanical construction of the frame work and incidentally thereby provide for the definite orientation of the seismograph.

(12) The lateral motion of the pens to be definitely limited to the width of the record sheet, but the steady mass to be free to move over a much greater range without striking against stops or encountering other obstacles or otherwise suffering derangement. If when writing near the edge of the sheet the pen should pass off the edge, provisions to be made so that it may return thereon and the record be resumed.

The essential details of this seismograph have mostly been fully designed, and some work has been done on the construction of a model to be subjected to the necessary test and further development of the instrument. Obviously, an instrument answering this description is appropriate only for the registration of feeble or remote earthquakes, although by an appropriate arrangement of the magnification the same instrument will be suitable for the registering of the greatest earthquakes.

In addition to the instrument described above, tentative plans are in mind for the development of a type of apparatus that may possibly meet the urgent demand for an instrument that can be placed in the hands of inexperienced observers and that will give a record simply of the local shocks and disturbances, and perhaps not at all of distant earthquakes. However, the record will indicate on a scale of some magnitude the intensity of the disturbance, the idea being to devise an instrument that can easily be cared for by inexperienced individuals and that will give a trustworthy measure of the intensity of local shocks. Seismologists are well aware of the importance of an instrument of this character, as well as its more or less complete unavailability at the present time. The Weather Bureau hopes to be able to develop something in this direction in the course of its work.

As no specific appropriation for seismological work has been provided, the work of supplying stations with seismographs will not be immediate. Fortunately, a large number of stations is not required for the detailed registration of all types of earthquakes, including especially those from remote foci. A few widely distributed stations suffice to secure all the information needed in such cases. On the other hand, if the Bureau is successful in developing a type of instrument that can be utilized by cooperative observers for registering the intensity of slight local shocks, a demand will arise for numerous stations equipped with this type of apparatus, and such a demand will be met as far as conditions permit.

PUBLICATION OF THE DATA

Earthquake reports received by the Weather Bureau will be published monthly in the "Monthly Weather Review." The non-instrumental and the instrumental reports will be grouped separately, and each group arranged alphabetically according to the state from which it was reported. The non-instrumental reports of each state and the instrumental records of each seismograph will be arranged according to date. The published data will be so grouped as to render it easy to answer the more frequent demands for information regarding the time, place, duration and intensity of earthquakes. The first publication in this form of seismological data collected under the auspices of the Weather Bureau appears in the December 1914 number of the "Monthly Weather Review."

THE WORK IN CALIFORNIA

Simply to serve as an illustration of the manner in which the work is being conducted, an outline of that now being done in California follows: Within the state of California there are twelve regular Weather Bureau stations. In addition, 167 cooperative observers have volunteered to report earthquakes to the San Francisco office, which is the section center. For several years past, various observers have reported earthquakes under "Miscellaneous Phenomena" in their monthly reports, and as such they have been printed in the "Monthly Bulletin" issued in San Francisco. An impetus has been given to this work by the greater attention recently given to seismology by the Bureau. During December, 1914, twelve of these stations reported earthquakes on four different days; during January, 1915, fifteen stations reported earthquakes on nine different days; while during February, 1915, eleven stations reported them on five different days. The importance of California as a field for seismological study is apparent from these figures, as well as from the occurrence of notable earthquakes during recent years. During December, 1914, more earthquakes were felt in California than in all the rest of the United States. Another feature which lends interest to seismological work in California is associated with the development of Mount Lassen into what Professor Holway, of the University of California, has found to be a true volcano, the only one within the borders of the United States. Though more than four-score eruptions of Mount Lassen have occurred during the past year, no earthquakes have been reported by competent cooperative observers in the vicinity. Press dispatches have contained references to earthquakes felt by residents in that region, but as yet no such report has come from any of the cooperative observers located there.

THE IMPORTANCE OF SEISMOLOGY

Were it simply to satisfy a popular curiosity, seismological work in the Weather Bureau would not be worth while. Though earthquakes have occurred from the beginnings of tradition, systematic seismology is not more than thirty or forty years old. Because it is a science still in its infancy, only a few general principles are as yet recognized, and some of these are still the subjects of dispute. It is hoped that the Weather Bureau will be able to assist in the work of developing seismology, and particularly in solving those problems with which the United States is concerned.

Of the various opportunities open to seismological investigation in America the most important is perhaps the preparation of a map of earthquake frequency, and a seismotectonic map, or one showing fault planes. The two will be closely related, since it is now generally recognized that practically all earthquakes occur along these fault planes. Such maps are of considerable importance to the engineer who is planning the construction of canals or locks, irrigation dams or channels, tunnels, bridges, or aqueducts. The French seismologist, Major De Montessus de Ballore, has published the only earthquake map of the United States now available, and as it is based simply upon well-defined disturbances of the past it is doubtless subject to considerable correction, since seismology takes account of the frequency as well as the intensity of earth shocks. Because of their positions with respect to epicenters, places like East Haddam, Conn., Newburyport, Mass., New Madrid, Mo., Lone Pine, Cal., Owens Lake, Cal., and the San Francisco Bay region are of seismological interest out of all proportion to their commercial importance. Reports from these districts may therefore be watched with growing interest.

Certain parts of the United States have unfortunately acquired a reputation for danger from earthquakes. However, residents of such regions take solace in the principle, now accepted by numerous seismologists, that since earthquakes most frequently result in a readjustment of stresses and strains along fault planes, a decided slipping or sliding must have afforded considerable relief, and therefore another earthquake is not likely soon to occur. On the other hand, residents of certain other regions find a certain sense of security in the fact that those regions have not recently been subject to shocks. The fallacy of such reasoning is pointed out by Professor W. H. Hobbs is his volume "Earthquakes," page 202, where he says, "From the New England region no earthquake of destructive violence has been recorded, but it is none the less a province of high seismicity and one which is likely at any time to be visited by a genuine disaster from this cause. The same statements apply with almost equal force to the entire Atlantic seaboard from Nova Scotia to Georgia. Other districts of the national domain which are especially likely to be disturbed by earthquakes are the central Mississippi valley, the valley of the St. Lawrence, and large areas not as yet well determined in the Great Basin and Pacific Coast regions of the Western States." The desirability of acquiring data to solve some of these problems is recognized by the Weather Bureau, and due consideration will be given them.

Another opportunity presented to the seismological investigator in the United States is that associated with the relation between earthquake frequency and secular changes of elevation or depression. Darwin and Humboldt both expressed the opinion that earthquakes are relatively frequent in districts now undergoing elevation or depression, a deduction fully verified by the Milne-Omori investigation of 8,300 Japanese earthquakes occurring between 1885 and 1892. If, as Major C. E. Dutton says, in the preface to his book "Earthquakes," "the earthquake is merely the elastic vibration of the earth-mass," the several regions of the United States which give evidence that secular elevation or depression is still in progress offer an alluring seismological field.

Other problems which must be solved in the development of seismology in America present themselves. The relation of earthquakes to mountains, to sea-coast, to ground relief, and to alluvial deposits are still subjects of considerable disagreement among authorities. When it is impossible to avoid fault planes in engineering projects certain types of construction doubtless will be found best adapted to withstand earth shocks. As little is known about the proximate cause of earthquakes, and nothing at all about their ultimate cause, the forecasting of earthquakes is wholly out of the question at the present time. Since the advent of the "New Seismology," or the study of earthquakes at a distance, it is recognized that there is work for scientists in many fields. While from a strictly meteorological point of view the Weather Bureau is not greatly interested, it considers itself fortunate in that it possesses the personnel and the necessary organization to render an important service in the collection of seismological data within the borders of the United States.

U. S. Weather Bureau
April 1, 1915

THE ERUPTION OF SAKURA-JIMA, 1914

By F. OMORI

I. INTRODUCTION

The Sakura-jima (Cherry Island), situated in Kagoshima Bay, and famous for the eruptions in 1779 and several earlier years, made a powerful outburst in January 1914 which may be counted, in point of the magnitude of disturbance, as one of the greatest volcanic catastrophes in modern times, and it was studied by many scientific men, including amongst the others such high volcanological authorities as Professor T. A. Jagger, Jr., and Mr. Frank A. Perret. The present author, who was despatched as a member of the Imperial Earthquake Investigation Committee, left Tokyo on January 14th, arrived in Kagoshima on the 16th, and remained in the stricken district till the 26th.[1] The following paragraphs give a short preliminary account, from the seismological point of view, of this Sakura-jima eruption, whose occurrence indicated the existence of a clear sequence among the various manifestations of the recent volcanic activity in Japan.

II. TOPOGRAPHY

(See figs. 1 and 2.)

The Sakura-jima is in shape an irregular ellipse, with the longer and shorter diameters of about 9.9 and 8.0 km. in the EW and NS directions approximately, the greatest extension being the length of 11.4 km. between the W-NW coasts and the Hakamagoshi. The latter, a square flat-top piece of ground 0.8 km. in length and 72 m. in height. so called because of the resemblance of its form to a trapezium, or back head of the Japanese trousers, when seen from the city of Kagoshima, is the only portion of the island which is sedimentary in formation, all the rest being covered by volcanic materials. Near the center of the island there are two high peaks, the Minami-dake

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[1] The author visited the scene of disturbance also in April and September, 1914.

(south crater) and the Kita-dake (north crater), respectively 1069.6 and 1133.5 meters in height, forming together with the Futanaka, or slightly depressed intermediate portion, the top ridge, about 1.8 km. in length running nearly in the S-N direction. Thus, from the E or W side, the island looks like a truncated triangle and a beautiful Fujiyama type outline with a flat top; while from the N or S side it appears in the form of a pointed cone. On the SE part of the island there is a flat well-preserved parasitic cone of the Nabe-yama (height. 328.4 m.), opening eastward and having a maximum base diameter of about 1.5 km. Among the side craters on the west the most conspicuous is the dome of Hikinohira (height, 553 m.). Again, the rocky protuberances of the Moe-zaki ("Burning promontory"), the Tatsu-zaki ("Dragon promontory"), Omoe-zaki ("Great burning promontory"), on the SW, the S and the NE side of the island, respectively, were formed by the lava streams attending the eruptions in the historical times. Further, the isle of Moe-jima ("Burning island") and other smaller ones situated off the NE coast of Sakura-jima are the results of the submarine outbursts which followed the great eruption in the sixth year of the Anei period (1779 A. C.), and are collectively known as the Anei Islands. The small isles of Karasu-jima and Okojima, off the W coast of Sakura-jima and off the Moe-zaki at its SW corner, respectively, are evidently the results of some of the former eruptions. Finally, as a special geographical feature of the island, is to be mentioned the existence of hot springs at Furusato, Yunohama, Arimura, and Krokami, on the SE coast, and of a mineral spring in the shallow sea water close to the back of Saido at the NW part of the island.

The population, distributed among twenty hamlets and habitations, situated all along the coast, belonged to two village districts of Higashi (Eastern) Sakura-jima and Nishi (Western) Sakura-jima, with the head offices respectively at Arimura and Yokoyama, the total population being about 2100.

III. SEA DEPTH AND MOUNTAIN SIZE.

The bay of Kagoshima, about 70 km. in length and 20 km. in width (fig. 1), is a depression in the NS direction, doubtless having a connection with the formation of the Kirishima-Sakura-jima volcanic chain, and is divided by the Sakura-jima distinctly into the southern and the northern portions. In the southern portion there exists a sort of terrace with the water depth up to fifty fathoms for the widths of about four and two kilometers, respectively, along the western, or Satsuma, coast and the eastern, or Osumi, coast; while the basin at the middle has a depth of 100 to 122 fathoms. On the other hand, in the northern portion, which is almost surrounded by steep coast, the depth of water is nearly uniform, ranging from about 70 to 107 fathoms. It is likely that the northern portion of the Kagoshima Bay is similar in nature to the deep lakes which are found behind the seacoast volcanoes of Usu-san and Tarumai-san, and its formation must be specially related to the history of the Sakura-jima; it being, in fact, in this nearly closed part of the bay that submarine eruptions produced three new islands ("Kamizukri-jima," or islands formed by the gods) in 764 A. C., and, again, eight new islands (the Anei-jima) in 1779-80 A. C. The western waterway or channel between the Sakura-jima and the coast of the Satsuma peninsula, along which the city of Kagoshima is situated, is 2.3 to 4.1 km. in width, with the maximum depth varying from 77 fathoms on the north to 38 fathoms on the south. The eastern waterway, on the other hand, was reduced (now blocked up) to a narrow strait at Seto, on the SE corner of the island, where for the length of about 1.6 km. the width was from 0.7 to 0.4 km., with the maximum depth of 45 fathoms.

From the above accounts it will be observed that the Sakura-jima is a small volcano rising out of a shallow sea, the total volume of the island above the sea level being 26.5 c. km., which will not be augmented by adding that of the portion below the latter. In magnitude the Sakura-jima is not much different from the Usu-San, situated on the Volcano Bay, but equivalent to only one-eleventh of the Asama-yama (*i. e.*, of the part above the plateau of Karuizawa on which it stands), and to one-fortieth of the Fuji-yama, the volumes of these last two mountains being about 290 and 1025 c. km. respectively. The smallness of size, coupled with the greatness of activity probably means the existence of the lava reservoir at an exceedingly near depth of a few kilometers, and the comparative weakness of the mountain frame for resisting the internal explosive condition, as is also the case with the Usu-san; and indicated unmistakable premonitory signs in the form of numerous earthquakes for several hours preceding the eruption in this year as well as that in 1779. Again, the eruptions would be very intense and of a lengthy duration, and throw out a considerable quantity of fluid lava, pumice, and ashes; but the individual explosions were not quite so powerful as those of the Asama-yama, which caused not rarely some damage to the buildings ten to fifteen kilometers distant from the crater by the violence of the air concussions.

IV. SIMULTANEOUS OR SUCCESSIVE ACTIVITY OF THE DIFFERENT VOLCANOES. (ANEI-TEMMEI-KANSEI EPOCH.)

The Japanese islands,[2] which form together a simple arc with steep descent on the convex side into the deep basin of the Pacific, may certainly be regarded as a system of volcanic chain or of earthquake zone which is still undergoing stress accumulation. When the latter reaches its limit, telluric disturbances may happen one after the other from various parts of the country, in the form of great earthquakes or volcanic outbursts, as the case may be. The epoch of the most violent eruptions in Japanese history was the interval of fourteen and one-half years in the Anei, Temmei, and Kansei Periods, namely, between 1777 and 1792. To begin with, the O-shima volcano (Mount Mihara) began eruptions on August 22, 1777 (the sixth year of Anei),[3] and lasted, with intermissions, till December 18, 1778, an enormous quantity of lava having been poured out. Then followed, on November 8, 1779, (the eighth year of Anei), the great eruption of the Sakura-jima, attended by remarkable lava outflows and formation of new islands; while the Aoga-shima, one of the Izu islands, commenced powerful outbursts on July 28, 1780, continuing till April 18, 1785. Before the activity of the latter volcano was brought to an end the Asama-yama broke out in strong eruptions, after May 9, 1783 (the third year of Temmei), culminating in a terrible down-rush of "volcanic avalanches" on August 5th. Finally, the eruption of the Unsen-dake, in Shimabara (Kyushu), began on February 12th, and terminated with a tremendous catastrophe on May 1, 1792 (the fourth year of Kansei), when the entire southern slope of the Mae-yama slipped down and was precipitated as an immense avalanche of rocks and earth into the sea of Ariake, producing the great water disturbances, or *tsunamis,* which resulted in the devastation along the coasts of the provinces of Hizen and Higo, with the loss of nearly fifteen thousand lives.

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[2] Limiting, for simplicity's sake, to the Nippon proper, or the four large islands of Honsiu, Shikoku, Kyusiu, and Hokkaido.

[3] See the Bulletin of the Imperial Earthquake Investigation Committee, 6, 13. The date of the eruption in question there was, by mistake, put on August 21, 1778.

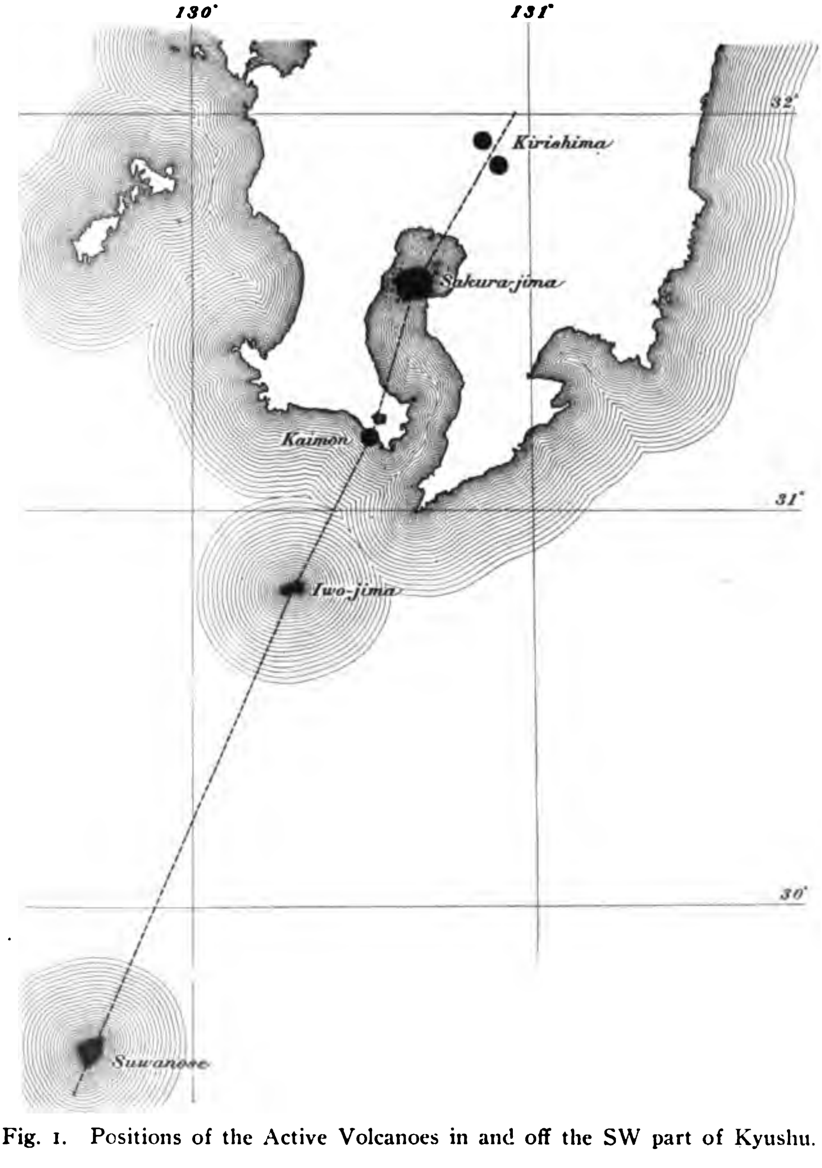


Fig. 1. Positions of the Active Volcanoes in and off the SW part of Kyushu.

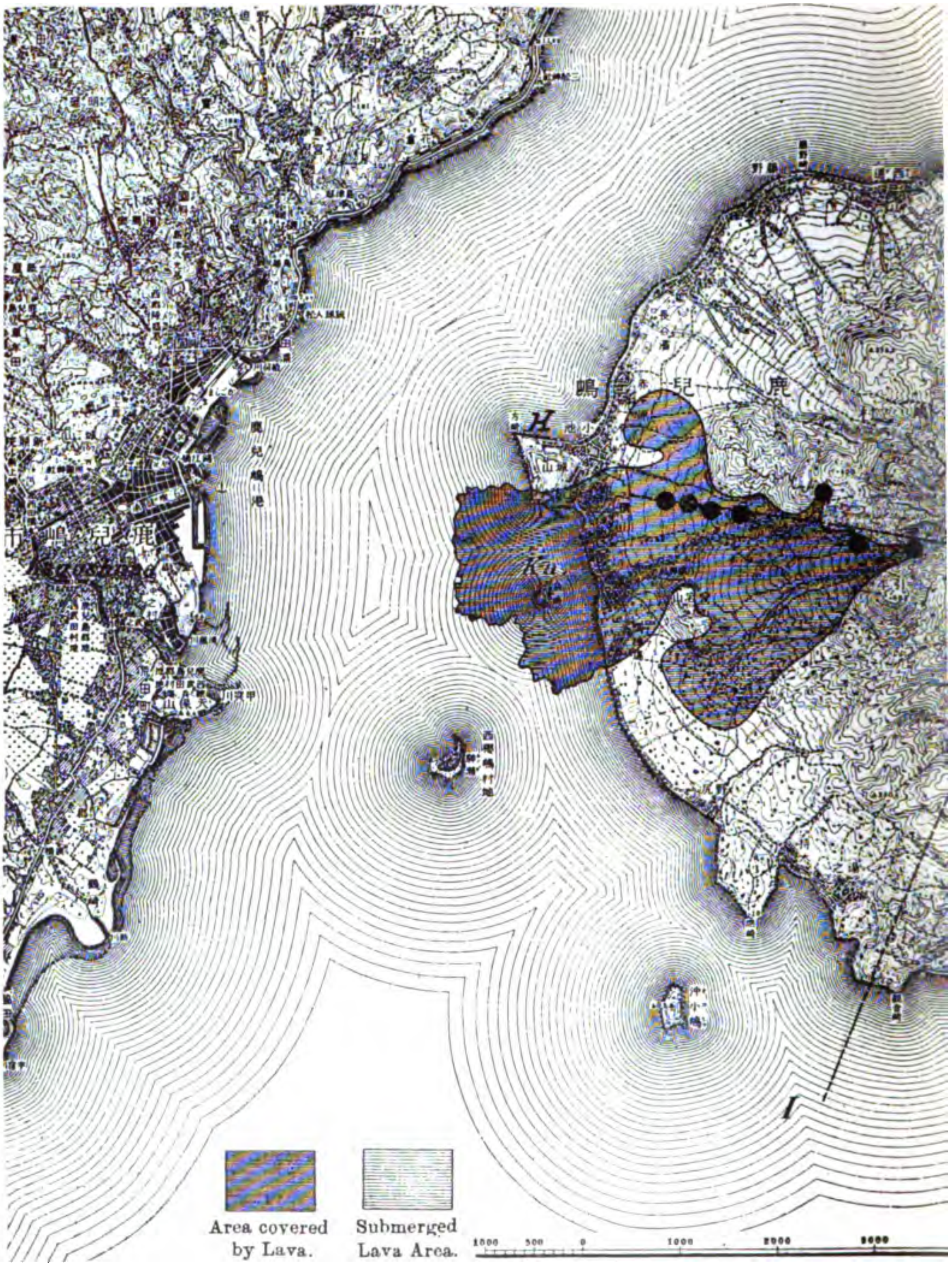
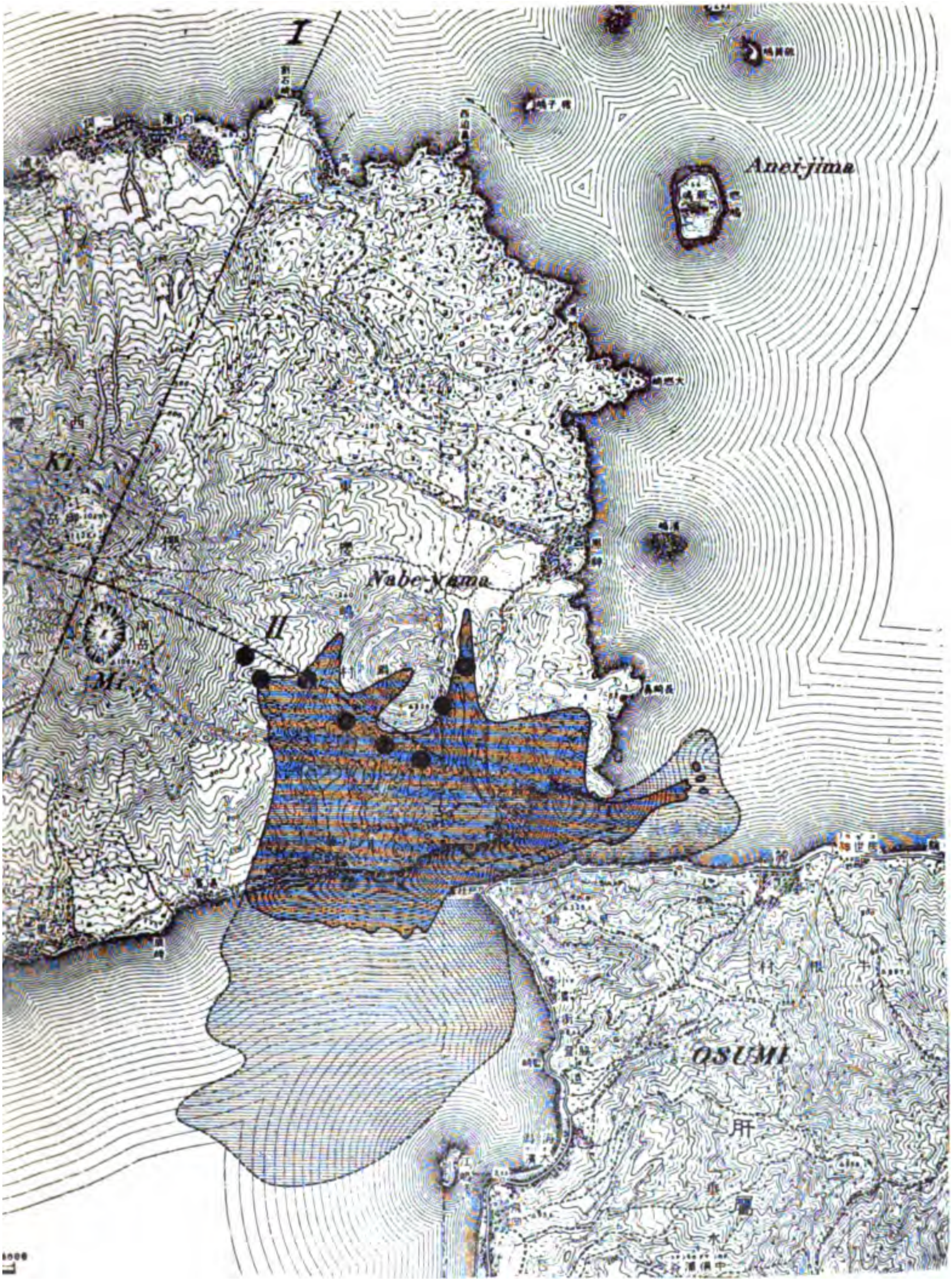


Fig. 2. Map of Sakura-jima showing the New Areas covered by **Lava an**
Mi, Minami-dake. ***Ki*, Kita-dake.**



the approximate positions of the Craterlets (May 1914). Scale in meters.
a, Karasu-jima. *H*, Hakamagoshi.

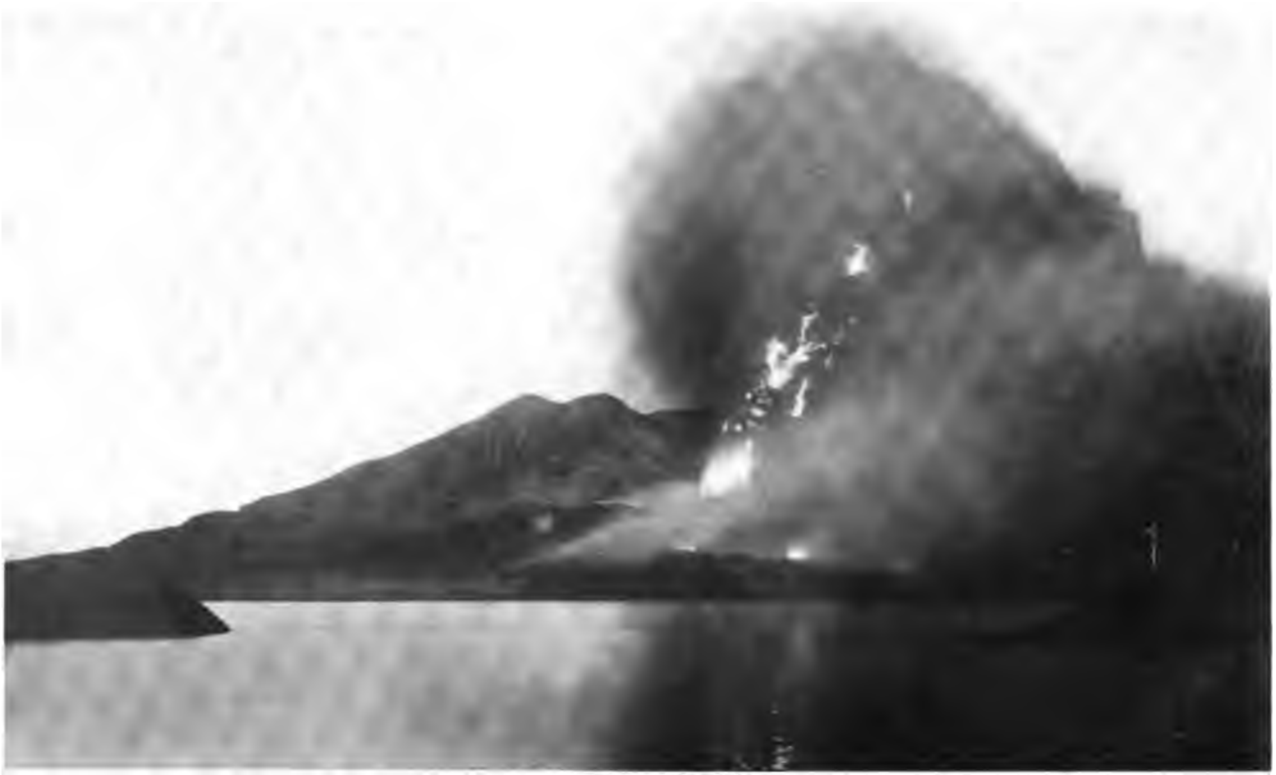


Fig. 3. Eruption of Sakura-jima.
Taken in the evening of January 15, 1914, from Kagoshima quey, showing luminous lava projection and lightning.
(Yuki, phot.)

Of the different mountains mentioned above, the Sakura-jima and the Unsen-dake are in Kyushu, while the three others—the O-shima, the Aoga-shima, the Asama-yama—belong to the Fuji volcanic chain, which, rising from the Pacific basin, meets the Japan arc nearly at the middle transversely. Yet, in spite of the wide distance between the two groups, the different volcanoes were thrown into great eruptions one after the other. This characteristic is being repeated at the present epoch.

V. RECENT VOLCANIC ACTIVITY AND SAKURA-JIMA ERUPTION.

Examination of the time distribution of the Asama-yama outbursts seems to indicate the recurrence of the epochs of the greatest eruptive frequency at a mean interval of about sixty-three and one-half years. Thus the double length of $63\frac{1}{2} \times 2 = 127$, or say 130 years, may also be regarded as a possible period in the frequency variation of the eruptions; and it is noteworthy that the Asama-yama, the O-shima and the Sakura-jima, which made no great outbursts after the Anei-Temmei times, have again exhibited, just after the lapse of 130 years, extraordinary activity within recent years.

In December 1907 the Yake-dake, on the boundary of the provinces of Hida and Shinano, commenced explosions; while from 1908 the Asama-yama caused numberless earthquakes and eruptions, many of which were of considerable violence. In 1912 the O-shima made magnificent firework-like lava outbursts, first in March-April and again in September-October. The explosions of the Yake-dake reached the climax of intensity in the summer of 1911, thence became gradually weaker, stopping completely since the summer of 1912. The eruption of the O-shima was also brought to an end in the spring of 1913; Asama-yama, again, evidently approaching the last phase of its present activity from about the latter epoch. The recent eruptive energy of the Fuji volcanic chain, manifested by the outbursts of these mountains, thus drawing to a close, the Kyushu volcanoes were thought, in obedience to the sequency of events in the Anei-Temmei-Kansei, to be now in their turn brought into activity, when, from May 19, 1913, small local earthquakes began to be frequently felt at the villages of Kakto, Masaki, etc., in the regions at the northern and western bases of the Kirishima-yama volcano, which stands on the boundary of the provinces of Osumi and Hyugaand, which had been quiet for the past ten years. This sudden appearance of seismic disturbances was at once interpreted as foreboding its eruptions and marking the transference of the volcanic activity to Kyushu; and the present author sent, under date of June 11, 1913, a semi-official letter to Mr. T. Taniguchi, the governor of the Kagoshima-ken, urging the necessity of setting up sensitive seismographs at the Kagoshima meteorological observatory and carrying on continuous tremor observations, as the prefectural districts, with many volcanoes, are often shaken by strong earthquakes, probably also disturbed by volcanic micro-tremors, and especially as the Kirishima-yama was entering upon a period of activity. In the meanwhile the seismic disturbance extended to the peninsular part of Satsuma, and at the end of June a strong earthquake with numerous after-shocks took place in the vicinity of the village of Ijuin, some sixteen kilometers to the W-NW from the city of Kagoshima. The Kirishima-yama broke finally in a strong explosion on November 8th, followed by a second one on December 9th, after which the present author decided, at the request of the governor of Kagoshima, to visit the volcano in question in the course of the next month. On January 8, 1914, the Kirishima-yama made the third strong explosion, and four days later, on the 12th, at about 10 a.m., there came to hand a telegram from the Kagoshima meteorological observatory, mentioning the occurrence of 337 earthquakes in the city between 3 a.m. on the 11th and 6 a.m. on the 12th. Startled by this intelligence, which evidently indicated a wonderful increase of the telluric disturbance, the author was on the point of sending a telegram to Kagoshima, giving instructions to carefully watch the condition of the Sakura-jima, which could be the only cause of the unusual seismic phenomena, when newspapers came announcing the eruption of the same mountain.

VI. PREMONITORY SIGNS.

Of great importance is the historical knowledge of the eruptions of different mountains, as we may thereby be much aided in considering the premonitory signs and the probable further course or consequence of outbursts from them. Unlike large destructive earthquakes, which originate along seismic zones, but are not repeated from one and the same center, the eruptions of a given volcano take place usually from the central crater or from new side vents, being anyhow thus localized to the mountain itself. Hence it may be that the great outbursts from a given volcano at widely different epochs resemble each other more or less, both in the eruptive phenomena and in the precursory events. Thus, for instance, in the eruptions of the Usu-san in

1910, 1822, and 1663, the first smoke explosions took place each time three or four days after the commencement of the premonitory shakings. In the case of the great Sakura-jima eruption of 1779 the earthquakes became very frequent from about 11 p.m. on November 7th; on the next day at about 11 a.m. the well waters in the island boiled up, waters were squeezed or shot out from the different sea beaches, and the sea water was turned purple in color; at 2 p.m. on the same day a column of gray smoke was thrown up vertically from Futanaka on the top, followed after a short time by loud detonations and eruptions almost simultaneously from both the northern and the southern sides of the mountain; the black smoke, which turned day into darkest night, being mixed with terrible fires projected high into the heavens and crossed by vertical and horizontal flashes of lightning. This description of the Anei eruption of the Sakura-jima can, almost without alterations, be applied to the recent great disturbance of the island, which I now proceed to sketch briefly.

I. THE EARTHQUAKES.

In the early morning of January 11, 1914, the people of the city of Kagoshima were generally aroused from sleep by an earthquake at about 3h 41m, which was nothing else than one of the premonitory shakings proceeding from the Sakura-jima, and was followed by numerous others. The annexed table gives the hourly numbers of the earthquakes registered with an ordinary Gray-Milne seismograph between the 11th and the 18th of January at the Kagoshima Meteorological Observatory ($\varphi = 31^\circ\ 36'$ N; $\lambda = 130^\circ\ 33'$ E), which stands on a hill 120 meters in height, outside the city, at a distance of 10.1 km. to the N76°W from the center of the Sakura-jima ($\varphi = 31^\circ\ 35'$ N; $\lambda = 130^\circ\ 39'$ E).

According to Table I, the average hourly earthquake frequency, which was 4.1 between 3 and 11 a.m. on the 11th, and was increased to 12.4 during the next nine hours, namely between 11 a.m. and 8 p.m., attained the highest value of 19.5 in the course of the further fourteen hours between 8 p.m. on the 11th and 10 a.m. on the 12th; the greatest hourly number of 28 and 27 having been reached respectively at 8-9 p.m. on the 11th and 3-4 a.m. on the 12th. The total number of the earthquakes registered at Kagoshima between 3 a.m. on the 11th and 10 a.m. on the 12th was 418. In Sakura-jima the earthquakes, which were many times more numerous than in Kagoshima, seem to have occurred already from the night of the 10th, becoming stronger from about 3 a.m. on the 11th. At Saido, situated at the NW coast of the island, 66 earthquakes were felt in the course of the single hour from noon till 1 p.m. on the 11th, against nine shocks registered at the meteorological observatory at Kagoshima. The earthquakes, which had large vertical components, were generally announced by a sound like that caused by the fall of a heavy body on the ground, immediately followed by tremblings. At 9 a.m. on the 11th the roads were already slightly damaged at several places. According to the account of the burgomaster of Higashi Sakura-jima village, there was

TABLE I.

HOURLY EARTHQUAKE NUMBER OBSERVED WITH GRAY-MILNE SEISMOGRAPH AT THE METEOROLOGICAL OBSERVATORY OF KAGOSHIMA, JANUARY 11-18, 1914.

Hour	Day							
	11	12	13	14	15	16	17	18
oh- 1h a.m.	..	21	..	1	..	..	..	..
1 - 2	..	9	..	..	..	..	..	..
2 - 3	..	7	..	1	..	..	1	..
3 - 4	3	27	..	..	..	..	..	..
4 - 5	8	13	..	..	..	1	..	..
5 - 6	5	20	..	..	..	2	2	1
6 - 7	0	21	..	..	..	..	..	..
7 - 8	2	13	..	..	..	1	..	..
8 - 9	7	25	..	..	..	..	..	..
9 - 10	5	24	1	..	..	..	..	..
10 - 11	3	17[4]	..	..	..	1	..	..
11 - 12	10	11	..	..	..	1	..	1
0 - 1 p.m.	9	6	..	..	..	2	..	..
1 - 2	12	3	..	..	1	..	..	1
2 - 3	14	5	..	..	..	1	..	1
3 - 4	14	2	..	..	..	..	..	1
4 - 5	16	2	3	..	..	..	..	.
5 - 6	15	2	..	..	..	..	..	..
6 - 7	10	1	..	...	2	2	..	1
7 - 8	12	0	..	..	3	..	..	..
8 - 9	28	1	..	..	..	..	..	..
9 - 10	19	..	..	..	1	..	..	..
10 - 11	26	..	..	..	1	..	..	..
11 - 12	20	..	11	..	1	..	..	..

[4] After 10 a.m. on the 12th the register is imperfect, as the volcanic detonations became thereafter gradually more intense, and the Gray-Milne seismograph was damaged by the strong shock at 6:30 p.m. on the evening of the same day.

at 5:30 a.m. on the 12th a most strong earthquake, accompanied by sharp vertical jerks.

2. HOT SPRINGS, ETC.

On the coast of Waki and Arimura, on the southern side of the island, from the early morning of the 11th, water began to issue copiously from several places. The temperature was so high that people had difficulty, at time of low water, in walking across the beaches. At the same time water was bubbling up from within the sea, while the hot spring of Arimura was thrown up in jets to a height of three feet. It is highly interesting that an analogous phenomenon also took place on the opposite side of the island, namely at Saido, where the issue of the naturally cold spring waters at the beach was considerably augmented, the striking change having been noticed at about 8:30 a.m. on the 12th by Mr. Hagiwara, headmaster of the village school, and many other people. Even on the 22d of January, when Mr. Hagiwara returned again to Saido, the waters were still so copiously flowing out that the point of issue was some twenty meters further inland than it had been formerly. This locality is known as Yuno-saki, literally "hot-water cape," it being likely that in old times there existed some hot springs, whose remnant may be the mineral spring referred to in section 2. One of the wells in the village had its water level, usually at a depth of eight or nine feet, raised to within five feet of the ground surface on the morning of the 12th.

3. SMOKE ISSUES

At about 8 a.m. on the 12th a column of white smoke suddenly shot up in the form of a pine tree from the top of the Minami-dake, while in the earlier hours of the morning, according to the observations from Kagoshima, several slender filaments of white vapour had been rising from above the layers of mist which shrouded the mountain. Again, according to the observations from the town of Tarumizu, on the coast of the province of Osumi, white smoke was floating like clouds, at about 2 p.m. on the 11th, around the SE mid-slope of the Sakura-jima.

The above were the unmistakable premonitory signs of the approaching catastrophe of the volcano, which previously had remained perfectly quiet and, for two decades or so, smokeless except, perhaps, a feeble issue of some white vapor once or twice in the year. Taking alarm from the frequent earthquakes, the majority of the inhabitants began to leave the island as early as the 11th, partly westward to the city of Kagoshima, and partly eastward to the town of Tarumizu and the neighboring villages in Osumi. The eruptions finally began on the 12th, at about 10 a.m. But, thanks to the timely warning taken by the people and the prompt and well directed measures of the prefectural authorities in despatching the several steamers which happened to be in port at the time to succour, the whole population of over 20,000 was safely brought out of danger, with the exception of the two clerks of the village office of Higashi Sakura-jima who, together with the burgòmaster, Mr. Kawakami, heroically remained till after the commencement of the eruptions and were drowned in attempting to swim across to the coast of Osumi. In the eruption of 1779 the number of the killed, under similar circumstances, was 144. The comparatively small mortality in the different Sakura-jima eruptions is probably in part due to the fact that the habitations are situated along the coast at some distance from the vents of the oubursts, and also to the fact that the latter do not attain full violence till some time after the commencement.

I can not here pass by without referring to the conduct of the director of the Kagoshima meteorological observatory, Mr. Y. Katsuno, who rendered an invaluable service in faithfully carrying on the seismographical and meteorological observations throughout the trying hours of general confusion and panic, but who made a curious mistake in insisting till the last moment on the supposed existence of the origin of the seismic disturbances in the opposite quarters, namely, in the direction of the Ijuin district, some sixteen kilometers to the NW from the city of Kagoshima. This Sakura-jima eruption was indeed one which could be predicted by common sense at least one entire day before. As a successful instance of management with respect to a volcanic catastrophe, I may mention the eruptions in 1910 of the Usu-san, in Hokkaido, which were attended with no casualty in consequence of the compulsory measures of the police inspector, Mr. Iida, who ordered the inhabitants in the vicinity to leave the threatened districts on the strength of my lecture on earthquakes and eruptions, given in 1902 at the Police and Prison Academy.

According to Table I, the first eruption took place about thirteen hours after the occurrence of the absolute maximum hourly earthquake frequency at 8-9 p.m. on the 11th. It is difficult to explain why a marked frequency minimum did occur at 2-3 a.m. on the 12th. It seems probable, however, that this minimum in the seismic frequency, which must denote a partial decrease in the underground stress, was occasioned by some preliminary smoke emissions from the mountain top and sides, or jetting out of waters from the different places along the coast.

VII. ERUPTIONS

The first outburst took place from the west side of the Sakura-jima at about 10 a.m., on the morning of the 12th, from a point above the Yokoyama-mura about 400 meters above sea level, followed after an interval of some ten minutes by an outburst from the south shoulder of the Nabe-yama, a parasitic cone, at the east side of the island. The outbursts, which were at the commencement accompanied by no special detonation, rapidly increased in magnitude and intensity.

According to the report of the Kagoshima meteorological observatory, which enjoys a full view of the Sakura-jima, red fires were seen at the base of the smoke column five minutes after the commencement of the eruption. The smoke ascended to a height of about 3,000 meters by 11 a.m., while the lava blocks, several of which had tails of steam and gases, were observed to be thrown out thickly from 11:30 a.m., when the *shoji* (paper-covered sliding doors) began to be shaken by the air vibrations. At 2:30 p.m., the whole island was enveloped in white and black smoke, the eruptive noises becoming more and more intense till at 3:30 p.m. the *explosive* detonations began to be heard.

The dense black smoke, which was projected finally, the weather being quiet, to a vertical height of over 20,000 feet above sea level, was traversed by electric discharges in various directions, while the incessant airquakes cooperated, so to speak, with the most frequent seismic convulsions of the ground in the development of the awful catastrophe. The panic in Kagoshima was greatly augmented by various ridiculous reports, one of which, relating to the supposed far-reaching fatal consequence of the poisonous volcanic gases, caused the people to get beyond the limit of a twenty-kilometer radial distance. This was most effective in driving the great majority of the seventy thousand inhabitants out of the city, who experienced hardships and privations in the sudden exodus, each endeavoring simply to get away as far as possible, on foot, in vehicles, or by railways. Another supposed danger was in the possible inrush of enormous *tsunami* (tidal waves), which might sweep away the entire city. When the afternoon of the 12th passed away under such disquieting circumstances, a new and real source of danger appeared in the form of a strong earthquake, which occurred at half past six o'clock and knocked down a great many of the stone partition and fencing walls, which abound in Kagoshima; a number of dwellings and warehouses, mostly of stone construction, in the lower and soft-soil part of the city and in the newly-made ground along the coast were partially or entirely destroyed. After this earthquake, the volcanic noises and the projection of red hot lava masses became markedly stronger, and the "explosive stage" reached its full intensity between about 11 p.m. on the 12th and 5 a.m. on the 13th, with the maximum at about 1 a.m. on the latter day. The detonations in Kagoshima during this interval were like those due to the quick firing of artillery pieces and were so loud that the prefectural officers had to stuff their ears with cotton. It was probably at this epoch that local hurricanes were produced by the eruptions, which seem to have been specially strong at the west end of the island in the neighborhood of the Hakamagoshi, upon which large mandarin orange trees, one foot or more in stem diameter, were uprooted and pieces of smashed wooden houses from the village of Yokoyama, situated at the east foot of the above-named plateau hill 72 meters in height, were found. After 10 a.m. on the 13th the violence of the explosions was greatly reduced, although still happening almost continuously. On the succeeding evening the volcano presented to the observers in Kagoshima a most magnificent sight, between about 8:15 and 8:30 the fiery materials being shot high, with brilliant displays of lightning, as it were, in a huge pillar, and converting the whole mountain slope over Yokoyama, from top to base, into one continuous zone of red hot masses. This was no other than the outflowing of the lava streams, and it was on this occasion that the houses in the village of Koike were burnt down from the precipitation of hot materials. Thereafter the noises were greatly reduced.

Even as late as January 16, 1914, when the author arrived in Kagoshima, the sight of the eruption was very beautiful and grand, the state on the west side being much the same as in fig. 3, which is a picture taken near the evening of the 15th from the harbor of Kagoshima. The eruptions on the west side of the island were practically brought to their end on January 25th, but those on the east, on the Nabe-yama side, have long kept up their energy, and are making strong outbursts from time to time even at the present day (August 1914).

LAVA STREAMS

About seven and eight principal craters were formed respectively at the west and east sides of the Sakura-jima, the uppermost one being in the former at an altitude of 500 meters, and in the latter at an altitude of 400 meters. The lavas which flowed out from both of these

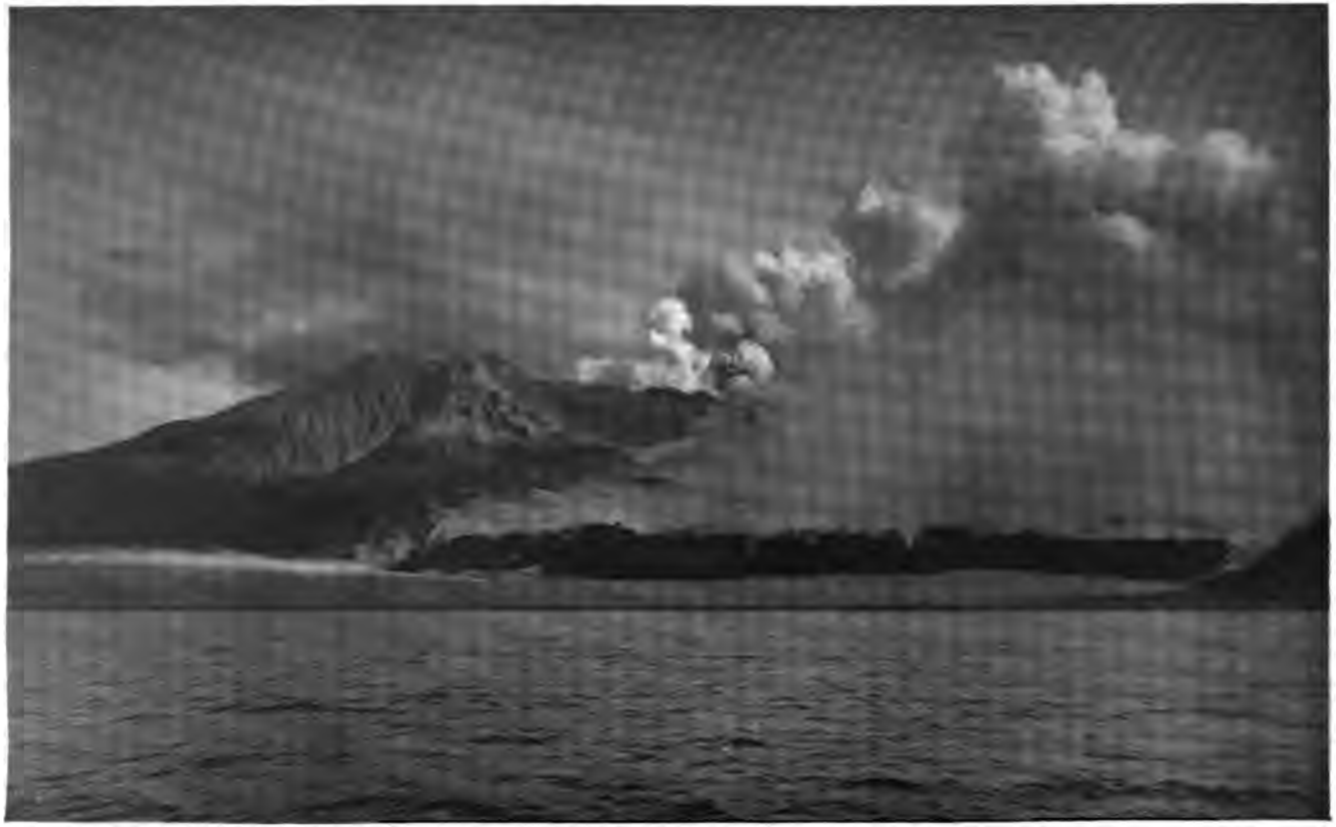


Fig. 4. Eruption of Sakura-jima (January 23, 1914), seen from the NW, showing Lava Outflow at the front. The principal Explosions are taking place from the back, or Nabe-yama side. (F. Omori, phot.)

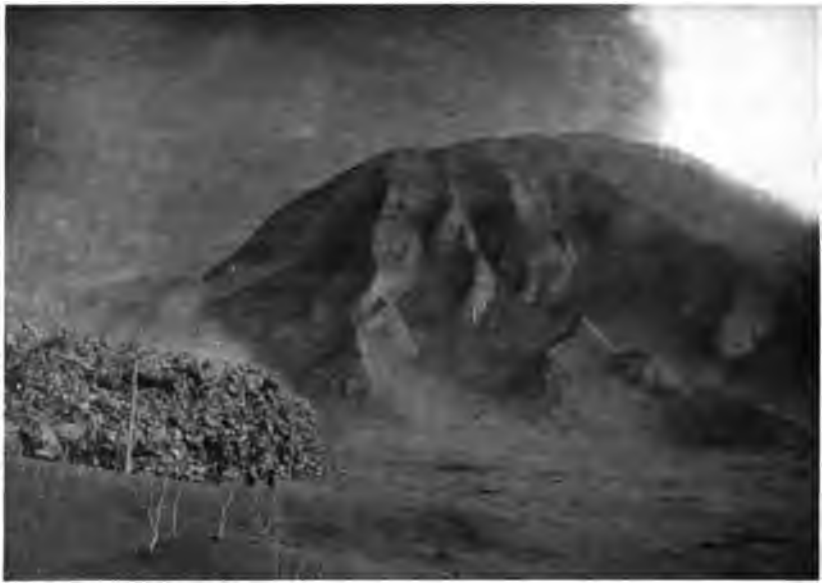


Fig. 5. Nabe-yama seen from north, showing a Lava "Stream" at the left side. January 16, 1914. (F. Omori, phot.)

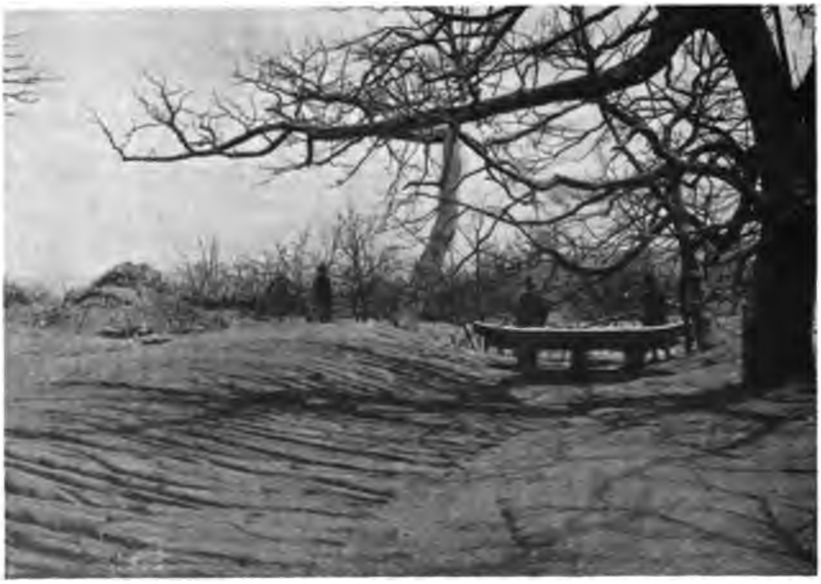


Fig. 6. Scene at the village of Kurokami, on the east coast of Sakura-jima. The thick precipitation of pumice and ashes buried the two posts of the stone "torii," or temple gate, 8 or 9 ft. in height, leaving only the horizontal top beams in air. Of the houses, only the roofs are left above the ashes. April 9, 1914. F. Omori, phot.)

groups were, like those of the Asama-yama, of very little fluidity, so that they are generally broken up into loose angular blocks. The main branch of the lava stream on the west side seems to have run down at 7 a.m. the next day through a distance of 2,000 meters in about twelve hours, to within 500 meters of the coast, reaching the same on the morning of the 16th. Thus the mean velocity of the descent of the lava stream in question was about 45 meters per hour during the first two and one-half days. The lava stream, which continued its forward progress into the sea, sending up an infinite number of small columns of pure white water vapor, reached at about noon of the 18th, small Karasu-jima, whose height was 20 meters and was at a distance of about 600 meters from the coast; giving the velocity of the lava motion about 21 meters per hour in the interval between the 16th and the 18th. When examined on the 20th, this islet had entirely disappeared under the lava in such a way that it was difficult to identify its former position. When examined on January 22d, the lava stream was moving, at the south base of the Hakamagoshi, with a speed of about one foot per hour.

On the other hand, the lava stream from the eastern, or Nabeyama side craterlets, quickly reached the comparatively deep Seto Strait between the SE end of the Sakura-jima the Sakkabira coast of the province of Osumi, and getting under the sea, was, when seen on January 16th, vigorously sending up masses of dense white smoke, the surface water temperature being 49° C. (measured on January 23d). The strait, whose width was narrowed by the lava to about twenty meters on January 24th, was finally blocked up on the 29th of the same month, the island of Sakura-jima being thus converted into an isthmus. When viewed at the beginning of April next, the lava mass filling the strait was bulged up into hills 50 meters or more in vertical height, still steadily pressing hard upon the former coast of Osumi. (See figs. 7 and 8.)

AREAS COVERED BY LAVA

Figure 2 indicates the areas covered at the commencement of May last by the lava which streamed out from the two groups of craterlets, the forms of the protuberances in the sea, both above and below water, being based on the surveys and soundings undertaken by the Hydrographical Department of the Imperial Navy. On the west side, the lava layers, whose maximum thickness or height was in the earlier days about 60 meters, completely burying under them the villages of

Yokoyama and Akamizu, reached the extreme extension of 4.8 km. in the EW direction, and projected 1,400 meters into the Kagoshima channel. As the depth of the latter, between the city of Kagoshima and the Hakamagoshi and the former isle of Karasu-jima, is generally less than 24 fathoms, or 44 meters, there was on this side no marked submarine extension of the lava, the top of whose end edge stands high up or is just visible out of the water surface. On the east of the Sakura-jima the three villages of Waki, Seto and Arimura were all buried under the lava streams, which flowed, on the north, also along the west shoulder and into the crater, of the Nabe-yama. A small hill, 103 meters in height, on the SE coast, which had not been covered by the lava at the end of January, was found entirely buried under it at the commencement of April. As the sea is 70 to 90 fathoms (120 to 160 meters) in depth, both on the NE and SW coast of the Sakura-jima, the projection of the lava stream into the sea which remains above the water level is only about 700 meters in maximum width, but the underwater extension is considerable, with an extreme distance of 3.4 km. between the S-SW end and the above-mentioned coast hill.

Even at the distances of 2.0 to 2.3 km. from the SE coast of the Sakura-jima under consideration, there were marked changes in the water depth revealed by the soundings; thus, for instance, at one point was found a depth of 25 fathoms instead of the former depth of 84 fathoms; at a second point, 26 fathoms instead of 88 fathoms; at a third, 36 fathoms instead of 96 fathoms, etc. These results seem to point to the conclusion that the submerged layer of the lava stream is in its middle and southern parts 50 to 60 fathoms or 90 to 110 meters in thickness. For the west, or Yokoyama side lava stream, the thickness of the portion projecting into the sea may be taken to be about 30 fathoms, or 55 meters. The approximate areas of the lava-covered tracts are as follows:

Area	Western, or Yokoyama, Lava Stream	Eastern, or Nabe-yama, Lava Stream	
	sq. km.	sq.km.	
Land (i. e., former land) area covered by lava	5.91	5.25	Sum
New lava area above water (or coast increase)	2.42	2.19	7.44
Submerged lava field	—	7.97	
Sum	8.33	15.41	

Thus, the total area of the eastern lava field, which is 15.41 sq. km. and of which 7.97 sq. km. belongs to the submerged portion, is nearly double that of the western, namely, 8.33 sq. km. The sum of the areas of the eastern and the western lava fields is 23.7 sq. km., which is equivalent almost exactly to one-third of the area of Sakura-jima. Assuming the mean thickness of the entire western side lava field and of the land portion of the eastern side lava field to be 40 meters each, and that of the remainder of the latter to be 100 meters, we get the following results:

	Volume
Western lava field	0.333 c. km.
Eastern lava field	1.226 c. km.
Sum	1.559 c. km.

The estimated total volume of the lava which flowed out from the two sides of the Sakura-jima is thus about 1.6 c. km., and equivalent to about one-seventeenth of the volume of the mountain, which is 26.5 c. km. The enormity of the Sakura-jima disturbances will be realized from a comparison with the great Temmei (1783) eruption of the Asama-yama; the area and the volume (under the assumption of the mean thickness of 40 meters) of the "Oni-oshidashi," or lava stream, on that occasion being 6.9 sq. km. and 0.27 c. km., which are equal to 1/3.4 and 1/6 of the corresponding quantities of the present Sakura-jima eruption. Moreover, in the Asama-yama catastrophe above referred to the volume of the lava outflow was only 1/1000 of the mountain volume.

PRECIPITATION OF LAVA FRAGMENTS AND ASHES

The villages of Koike and Akobara, situated on the west coast to the north of Hakamagoshi, were, although outside the lava stream areas, completely crushed, burnt, and buried by the showers of more or less pumicose hot lava fragments projected from the craterlets. The scene in these neighborhoods was desolate and barren in the extreme, these stones, which also smashed the trees into terrible condition, having made an innumerable number of the so-called conical holes of various dimensions on the Hakamagoshi and in the tracts immediately to its N and E bases. These facts, in conjunction with the probable gush of hot volcanic gases, seem to indicate that the local explosive effects attending the eruptions were specially strong at the west side craterlets.

The precipitation of pumice and ashes was very abundant in the eastern part of the island, being deepest at and about Kurokami, where it amounted to six feet or more and buried the houses nearly to the roofs. Figure 6 illustrates how the gate of the village temple had the two upright stone columns, some eight or nine feet in height, buried under the pumice and ashes, only the two horizontal beams remaining in the air. On account of the prevalence of the westerly winds in the higher atmospheric region all the year round, the ashes of the different volcanic eruptions in Japan are generally carried eastward, whatever the surface winds may be. Thus the ashes of the great Sakura-jima eruption of 1779 reached Osaka, Nagoya and Yedo (Tokyo). On the present occasion the ash-precipitation reached the Bonin Islands to the SE and extended to the NE over Kyushu, Shikoku, and the whole of the Main Island to the west of Mito and Utsunomiya, the extreme eastward radial distance being over 1,200 km. Thus the ash-precipitation was very slight and under 3 mm. in Kagoshima, situated close to the west of the Sakura-jima, while it was very heavy in the northern and central parts of the province of Osumi, the amount ranging from three or five inches to over three feet. The principal axis of the ash-precipitation extended from the Sakura-jima in a direction of E slightly S to the vicinity of the town of Shibushi on the Ariake bay. Making the planimeter estimations of the areas enclosed by the different iso-precipitation curves drawn on a map, based on the measurements of the thickness at a number of places in the S part of Kyushu, the total amount of the pumice and ashes which fell in the latter comes out to be only about 0.62 c. km., equivalent to 40 per cent of the total volume of the lava outflow. This is a sufficiently large quantity, which, if distributed over the whole extension of the city of Tokyo, about 80 sq. km. in area, would give a mean thickness of about ten feet.

The total sum of the volumes of the pumice and ashes and the lava outflow thus amounts to 1.56 + 0.62 = 2.2 c. km., which is equivalent to one-twelfth of the volume of the whole mountain.

The specific gravity of the ashes, which were acidic, determined from the specimens collected in Kagoshima and Sakura-jima, varied from 0.9 to 1.2, giving the mean value of 1.00. Again, the specific gravity of the lava pieces and bombs found at the west, or Yokoyama side, varied mostly between 1.06 and 1.63, with the mean value of 1.4; while that for the specimens from the eastern, or Nabe-yama side, was between 1.92 and 2.81, with the high mean 2.4.

VIII. STRONG EARTHQUAKE AND SMALL "TSUNAMI"

In the strong earthquake of January 12th, at half-past six o'clock in the evening, seven persons were killed, while walking in the city streets, by the outward overturning of stone fences, and twelve others, trying to escape into the country, by the crumbling of high perpendicular roadside cliffs of soft tuff at a place called Tenjinga-seto, outside of Kagoshima. This seismic disturbance, whose preliminary tremor reached Tokyo at 6:30:21 p.m.; was obviously of volcanic origin, being, however, unusually large in magnitude. Judging from the tromometer diagrams obtained in Tokyo, it is evident that the Kagoshima (or Sakura-jima, provisionally) earthquake in question must have been several times larger in magnitude than the strong Asama-yama earthquakes of May 26, 1908,[5] and of July 16, 1912, or of the strong Usu-san earthquake of July 24, 1910, at 3:49 p.m.,[6] which seemed to represent the limiting intensity and size of a volcanic earthquake. A special character of the Kagoshima earthquake is that the intensity of motion was nowhere very severe, the seismic damage in the Sakura-jima itself being, probably on account of the rocky nature of the ground, considerably less than in the lower part of the city of Kagoshima. It is thus evident that the earthquake must have been of very deep origin; and it was probably the result rather of the stress accumulation along the whole volcanic chain in the southern Kyushu, being not at all the local shock connected simply with the eruptions of the individual Sakura-jima. This supposition seems probable, as one month later, on February 13th, at 3:37:19 p.m.[7] there took place an earthquake, also of no insignificant magnitude, during the activity of the Iwo-jima, another of the same volcanic chain. Strong volcanic earthquakes may possibly be divided into the two categories of (1) local shock, necessarily of shallow focal depth, and (2) extensive earthquake, of great depth. In both of these cases the surface intensity of the seismic motion would not be so high as in great destructive earthquakes of tectonic origin.

In the city of Kagoshima, which is situated to the west of the Sakura-jima, the earthquake damage to the various structures indicated very clearly the longitudinal nature of the shock. Thus the stone fences, which were in the E-W direction, even though of very unstable dimensions, remained standing, while those in the N-S direction were very often overturned. On the other hand in the cases of houses with plastered or paper-covered walls damage was of a different nature: that is to say, the walls in the E-W direction were much broken by the two systems of mutually rectangular cracks, while those in the N-S direction remained mostly intact. According to the ordinary seismograph diagram obtained at the Kagoshima meteorological observatory, the very first earthquake displacement of the strong shock under consideration was directed toward W-NW, or away from the Sakura-jima.

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[5] Bulletin I. E. I. C., 6, figs. 36 and 37.

[6] Ibid., 5, 15.

[7] Time of earthquake occurrence indicated by the tromometers in Tokyo.

The 12th of January happened to be the day of full moon, and the tide was high in the evening, when the strong earthquake took place. Probably one or one and one-half hours after the occurrence of the earthquake the waters in the harbor of Kagoshima, whose level was then only about one and one-half feet below the top surface of the quay wall, flowed a little over the latter and partially washed the coast street, a few boats being thereby damaged. This disturbance of the sea waters is to be regarded as a small *tsunami,* whose direct cause was, however, not in the strong earthquake before mentioned, but probably in a small sudden settlement or depression of the bay bottom. (See also §10.)

IX. TROMOMETER OBSERVATION OF ERUPTIONS

A two-component horizontal tremor-recorder, magnifying 200 times, which the author took with him on his first visit to Sakura-jima in January, was temporarily set up on the solid stone formation in the instrument room of the Weight and Measure Department, in the prefectural compound, and the observations, which were under the care of my assistant, Mr. Krosaka, were started on the 16th of the same month and continued until February 8th, when the seismograph was removed to the village of Furusato in the Sakura-jima. The result of the registration is embodied in Table II, which is the list of the daily numbers during this interval of the larger and smaller volcanic eruptions, and of the non-eruptive volcanic earthquakes and those of neighboring origin, the photographically enlarged illustrative diagrams being given in figs. 9 and 10.

Thus the "large disturbances," which were at first very numerous, with the daily frequency of 53 to 74 between the 17th and 20th (January), thereafter markedly decreased, the daily frequency between the 21st and 27th being 29 to 40. After January 28th the decrease was equally remarkable, the mean daily frequency during the next eleven days being only 4.7. On the other hand frequency of the small disturbances indicated a tendency increasing or decreasing in inverse proportion to that of the strong eruptions. The daily number of the non-eruptive volcanic earthquakes also shows a similar tendency of alternating the epoch of maximum frequency with those of the strong eruptions. I must here state that the "large disturbance" here means simply an outburst whose earthquake motion was comparatively large (double amplitude = 0.1 mm. or so), and the "small disturbance" one whose earthquake motion was small (double amplitude = 0.01 mm. or

TABLE II.

DAILY NUMBERS OF THE ERUPTIONS AND EARTHQUAKES OF THE SAKURA-JIMA, INSTRUMENTALLY REGISTERED AT KAGOSHIMA, JANUARY 16 TO FEBRUARY 7, 1914.

Date (1914)		Eruptions		Volcanic Earthquakes not accompanied by eruptions		Earthquakes of neighboring origin	
		Larger	Smaller	Larger	Smaller	Larger	Smaller
January	16[8]	13	..	1	..	..	..
	17	67	1	4	5	2	..
	18	53	84	7	9	4	..
	19	74	39	1	2	..	..
	20	65	78	1	2	2	..
	21	37	77	2	4	1	..
	22	29	93	3	..	1	..
	23	34	82	1	1	..	..
	24	40	78	..	1	..	..
	25	36	63	3	1	1	..
	26	29	101	1	..	..	..
	27	35	136	..	4	..	..
	28	14	148	2	..	..	..
	29	17	147	3	5	..	..
	30	1	144	..	3	..	..
	31[9]	5	130	1	2	..	..
February	1	6	117	2	7	..	..
	2	4	108	..	1	..	..
	3	2	60	..	2	..	..
	4	..	105	1	4	..	..
	5	..	82	..	..	..	..
	6	2	160	2	2	..	..
	7	1	63	1	..	..	..

[8] Registration commenced at 6h 6m p.m.

[9] Volcanic tremors very marked between 9 a.m. and 10 p.m.

so); in either case no reference being made to the intensity of the sound. A noteworthy fact was that the explosions, accompanied by very loud detonations, like for instance the outburst from one of the Nabe-yama side craterlets on February 7th, at 11:25 a.m., which startled the inhabitants of Kagoshima and neighboring places, caused always a very small amount of the earthquake motion, generally undistinguishable from the micro-tremors.[10]. Thus, in the present case there are two kinds of eruptions, as follows: (1) the explosions with loud detonations, which cause only a very slight amount of seismic effects; and (2) the non-detonative eruptions, which are accompanied by comparatively large earth vibrations. It is likely that the (1) eruptions produce the intense noises by suddenly rupturing or breaking open the partially solidified lava bottoms of the craterlets, and are more of the nature of surface action; while the (2) eruptions are more important phenomena, and consist in powerful projections of ashes and gases along pre-existing channels of deep extension. It follows, according to this point of view, that the mere abundance of the loud detonations, which continued to make the people of Kagoshima uneasy from time to time, is to be represented by the high frequency of the "small disturbance," and by no means signified any material augmentation in the activity of the Sakura-jima. If the frequency of the "large disturbances" be assumed to give a measure of the degree or amount of the eruptive activity of the volcano, it will be seen from the above list that the latter is steadily tending back to the equilibrium condition. The rate of decrease of the "strong disturbance" at the end of March 1914 was only about 1/6000 of that on January 16th-17th, or roughly some 1/10,000 of what existed at the commencement of the eruptions.

X. DEPRESSION OF COAST AND ELEVATION OF BAY WATER LEVEL

According to the tide-gauge readings at the Kagoshima harbor in 1903 and 1904, the highest sea level was 12.3 *shaku*,[11] which took place on September 11 and October 10, 1904, the maximum daily range or the height difference between the low and high waters being about 11.5 *shaku*. After the commencement of the Sakura-jima eruption in January 1914 there took place abnormal disturbances in the sea level, a height of 12.2 *shaku* having been realized on the occasion of the high tide of March 13th (seventeenth lunar day), inundating the lower

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[10] Similar peculiarity was observed to a certain extent also in the case of the Asama-yama eruptions.

[11] 1 shaku = 1/3.3 meter = 1 foot very nearly.

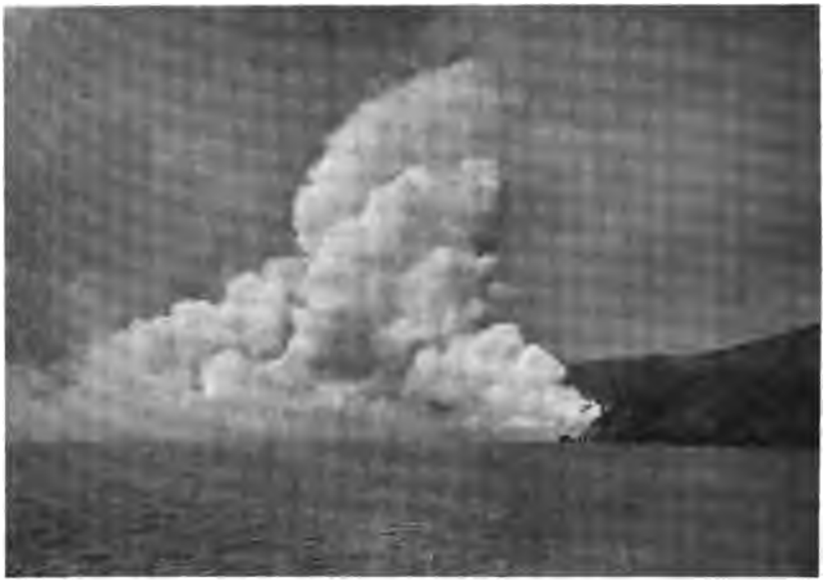

Fig. 7. Seto Strait, between Sakura-jima and the Province of Osumi, before its closure. (January 16, 1914. F. Omori, phot.)

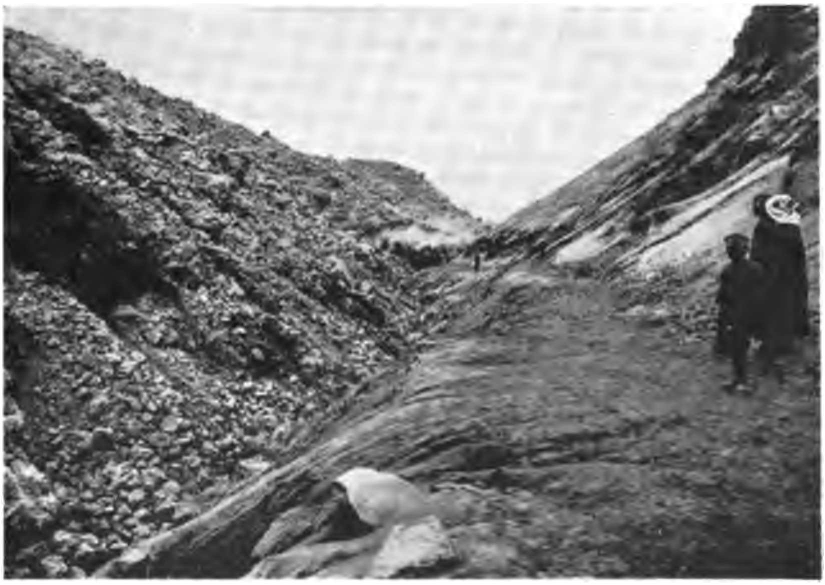

Fig 8. Blocking up of Seto Strait, originally 0.7 km. in width and 45 fathoms in depth. The right-hand slope is the former coast of Osumi, while the left-hand side hill, over 50 m. in height, is the lava which flowed down from the Sakura-jima. (April 10, 1914. F. Omori, phot.)

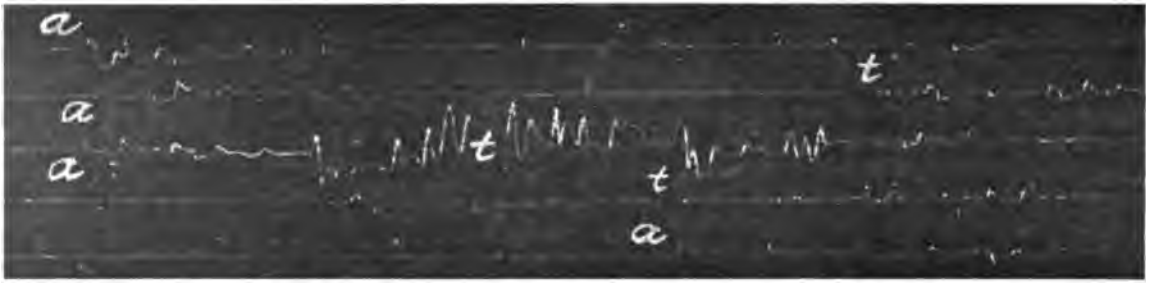

Fig. 9. Tremor recorder observation of Sakura-jima Eruptions at Prefectural Compound, Kagoshima, giving the longitudinal component diagram of "small disturbances" on Jan. 20, 1914. Magnification = 673. Time scale: 1 Minute = 188 mm. (This illustration reduced from 188 mm. to 151 mm.) *a*, Commencement of an eruption. *t*, Minute (time) cutting.

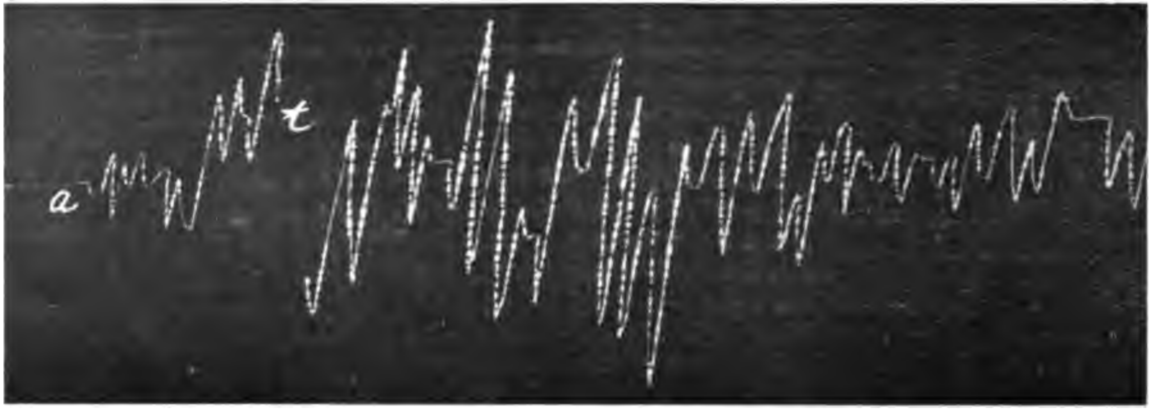

Fig. 10. Tremor recorder observation of Sakura-jima Eruptions at Prefectural Compound, Kagoshima, giving the longitudinal component diagram of a "large disturbance" on Jan. 20, 1914. Magnification = 820. Time scale 1 Minute = 225 mm. (This illustration reduced from 188 mm. to 151 mm.)

parts of the city of Kagoshima and causing some damage to the salt-fields along the beaches of the town of Kajiki and other places. This overflow of the sea waters, quite unusual except in the autumn months, seems to have been the consequence of a general elevation of the mean sea level in the northern part of the bay, the difference between the ebb and flow being 10.4 *shaku,* or 1.1 *shaku* less than the maximum limit before found. In the following table are compared the approximate mean monthly heights of the sea surface at the Kagoshima harbor between February 1914[12] and February 1915, with those for the corresponding months in 1903 and 1904.

TABLE III.

Month	(I) Height of Mean Sea Level (1903 and 1904)	(II) Height of Mean Sea Level after the Eruption (1914 and 1915)	Difference (II)-(I)
January	5.29 *shaku*[11]	— (1914)	—
February	5.01	6.43 *shaku*	1.42 *shaku*
March	5.28	6.68	1.40
April	5.24	6.54	1.30
May	5.23	6.69	1.46
June	5.60	6.99	1.39
July	5.95	7.16	1.21
August	6.04	7.71	1.67
September	6.11	8.11	2.00
October	5.94	8.10	2.16
November	5.35	8.35	3.00
December	5.13	8.10	2.97
January	5.29	8.06 (1915)	2.77
February	5.01	7.73	2.72

From the above table it will be seen that the mean monthly height of the sea level at Kagoshima was, between February and July in 1914, about 1.4 feet higher than in the corresponding months in 1903 and 1904; this difference having been increased up to the maximum of three feet in November 1914, since when the amount seems to be again beginning gradually and slightly to decrease.

The increase in level of the Kagoshima sea water, which was also the case for the several years succeeding the Sakura-jima eruption in 1779, seems to be due to the depression of the ground under and about the northern part of the Kagoshima bay in consequence of the decline of the eruptive force and the outflow of enormous lava masses, which, if distributed over the island of Sakura-jima, would give a uniform thickness or depth of about 30 meters. Compared with the height determined in 1892, the results of the leveling now being repeated by the Military Survey Department at the suggestion of the Imperial Earthquake Investigation Committee, it follows that there has been a general depression, whose amount was (in the summer of 1914) about 0.4 meter at the coast of the city of Kagoshima, and increased up to 0.82 meter at a small promontory of Osaki-no-hama, about 10 km. northward along the coast. This result is in fair agreement with the variation in the height of the sea level, whose amount was, in February to July 1914, about 1.4 feet or 43 cm., at Kagoshima. It is likely that it will be several years before the ground about the Sakura-jima regains its former level, probably to be followed by some elevation culminating in a new eruption. Detailed discussion on the sea level variation at Kagoshima and the depression of the ground is reserved for a future communication.

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[12] The tide gauge reading at the Kagoshima harbor was started again by the Prefectural Engineering Department, February 14, 1914.

XI. Arrangement of Craterlets

(Fig. 2.)

The different new craterlets on both sides of the Sakura-jima are arranged evidently along a zone (II-II), which extends through the center of the island in a W-NW and E-SE direction, and to which also belongs the extinct parasitic cone of the Nabe-yama on the SE and the dome of the Hikinohira and the Karasu-jima (now covered-up) on the W. This zone, whose original formation probably dates back to the epoch of the construction of the mountain itself, is approximately at right angles to the line I-I, which connects the Sakura-jima with the active Krishima-yama on the N-NE and the dormant Kaimon-dake, or Satsuma-Fuji, on the S-SW. It is hereby to be noticed that the line I-I represents a part of the extensive South Kyushu volcanic chain and is, in this respect, of primary importance in comparison with the zone II-II, which, not belonging to such a chain, is to be regarded as marking a system of secondary fracture or crack limited to the island itself.

The formation of numerous craterlets on two opposite flanks of the island was also the case with the eruptions of 1779 and 1476; it being obviously easier for the eruptive energy of the Sakura-jima to find vents at or near the base of the mountain than to push up the lava to its top.

XII. COURSE OF ERUPTIVE PHENOMENA

It is certainly a very difficult problem, involving great responsibility to the public, for several years to come, to forecast the future condition of a volcano, in complex activity, with reference to the possibility or non-possibility of the repetition of the strong outbursts, and the existence or non-existence of danger to the inhabitants at the mountain base. Yet, as a seismological member of the Imperial Earthquake Investigation Committee, I had to give out in distinct form my opinions on this question as soon as possible, in relation to the outbursts of the Sakura-jima, which were obviously to be continued for several months. With respect to the city of Kagoshima the matter was perfectly simple, as explained in the next section. It was, however, after long consideration that the author decided, on the 20th of January, or one week after the commencement of the eruption, to allow the fugitives from Nojiri, Furusato, etc., on the SW coast, and those from Take, Fujino, etc., on the NW coast of the Sakura-jima, to return of their own choice to the respective villages where the ash-precipitation had not been excessive; cautioning them to be careful should frequent or strong earthquake shocks be repeated in the island. Now, the catastrophe of November 8, 1779 (section 2), was followed, in the course of one complete year beginning with November 21st, or the end of two weeks from the date of commencement of the eruption, by the formation of eight new islands off the NE side of the Sakura-jima, each time accompanied by some sea-water disturbances resulting in a small *tsunami*. The possibility of submarine after-eruptions gave the people of Kagoshima some uneasiness, giving rise at the end of January even to a false report of the formation of a new island off the SW coast of the Sakura-jima. The reasoning by which I had denied the probability of the repetition, in the present instance, of this particular sort of volcanic phenomenon, was as follows: The craterlets in the eruption of 1779 were found on the S and NE sides of the island, or roughly parallel to the general direction I-I (fig. 2) of the volcanic chain, along which, and especially in the northern part of the bay, between the two volcanoes of the Sakura-jima and the Kirishima-yama, submarine eruptions may take place, as in 1779 and 764; while in the present case the craterlets have been formed along a secondary line of weakness, and not along a volcanic chain, implying the impossibility of occurrence of new eruptions from points on extension either toward Kagoshima or toward Osumi. As a matter of fact there has been so far no formation of a new island.

XIII. CITY OF KAGOSHIMA AND ERUPTION

The city of Kagoshima, although near enough to the Sakura-jima, is in reality in a position not to be damaged by the eruptions of the latter, and, on receipt of the news of the first eruption on January 12th, I sent telegrams at once to the Governor of the Kagoshima Prefecture and the office of the daily newspaper, the "Kagoshima Asahi," to the effect that in Kagoshima there was nothing to be feared from the eruption. The following is a note which I published in Kagoshima on the 16th, immediately after my arrival in the city:

Eruption: The new craterlets are, even the nearest of them, at a distance of about 6 km. from Kagoshima. The projection or precipitation of lava pieces, 70 or 80 grams in weight, is limited, even in the strong Asama-yama explosions, to the radial distance of some 4 km. Hence in the Sakura-jima outbursts, in which the individual explosions are not so powerful as those of the Asama-yama, there will be no risk in the city arising from the fall of the lava pieces of non-insignificant dimensions.

Earthquakes: The earthquakes so frequently occurring since the 11th are disturbances of volcanic nature, and even when very strong never attain the intensity of a great destructive earthquake, *i. e.*, will not be able to destroy the ordinary Japanese wooden houses. Brick chimneys, stone fence-walls, etc., of unstable dimensions are, however, easily broken, and care must be paid to make them strong enough.

Tsunami (sea waves): Should the greater portion of the Sakura-jima be suddenly precipitated into the bay, then there would be risk of the production of *tsunami*. As, however, there is no prospect of the occurrence of such a convulsion, there is no need of apprehending a great *tsunami*.

Volcanic gases: Even if the volcanic gases be strongly thrown toward Kagoshima, there is no risk of poisoning or suffocation.

The people of Kagoshima, which had been nearly a deserted city since the 12th, began gradually to come back on and after the 16th, while the activity of the Sakura-jima continued to be reduced steadily since the 14th (January). The eruptions of the western, or Yokoyama side, craterlets were brought practically to an end on January 25th; but some of the craterlets on the eastern, or Nabe-yama side, are still giving forth strong eruptions from time to time even up to the present day. As shown in section 7, the quantity of lava outflow from the eastern craterlets group is nearly double that from the western craterlets group, and taking together the great eruptions of 1476, 1779 and 1914 it is seen that the greatest lava outflow took place on the eastern side of the line I-I (fig. 2). This fact may have some connection with the arrangement of the underground lava reservoirs.

XIV. Activity Along South Kyushu Volcanic Chain

(Fig. 1.)

In the earlier parts of the present year there have been several outbursts in succession from the South Kyushu volcanic chain. Thus, the strong explosion of the Kirishima-yama on January 8th was quickly followed by the great Sakura-jima eruption of January 12th. Then the Iwo-jima (or Kikai-ga-shima, well known in Japanese history), situated off the south coast of Satsuma, made eruptions on February 13th, accompanied by several earthquakes, one of which was of a fairly large magnitude (section 8). Finally, the Suwanose-jima, situated further southward, made eruptions on March 21st. These four volcanoes, which together with the Kaimon-dake, form a nearly straight line, are at successive distances as follows:

Kirishima to Sakura-jima	45 km.
Sakura-jima to Kaimon-dake	46 km.
Kaimon-dake to Iwo-jima	50 km.
Iwo-jima to Suwanose-jima	147 km.

These eruptions which thus proceeded, as Professor Jagger remarks, from north to south, have probably brought the volcanic activity in this part of Kyushu to an end for the time, which apparently had the effect of changing the site of volcanic outbursts again to the Fuji volcanic zone, the Oshima having made, after a quiescence of about one and one-half years, very powerful lava eruptions for about seven days between May 15th and 22d (1914).

EARTHQUAKES IN SOUTH CAROLINA DURING 1914.

By STEPHEN TABER

Eight earthquakes, having their epicenters within the boundaries of South Carolina, were recorded during the year 1914, and the Georgia earthquake of March 5th was felt in the northwestern portion of the state. Six of the disturbances occurred in the seismic area near Charleston, and the other two in the Piedmont region. Last year the writer published the results of a detailed investigation of the cause of earthquakes in the Atlantic Coastal Plain near Charleston and of the factors controlling fluctuations in the seismic activity of that area. The paper [1] was accompanied by a tabulated list of over four hundred shocks, nearly all recorded since 1886. In the present paper that list is completed down to the close of the year 1914, and the new data are briefly discussed.

In the Charleston area, seismic activity was noticeably greater than during the previous year, but did not equal the record for 1912. Six shocks occurred in 1914, as compared with four in 1913 and eight in 1912; and the earthquake of September 22d had a greater intensity (V, R.-F.) than any felt since the shock of June 12, 1912, which had an intensity of VII.

The first earthquake recorded in the Charleston area during 1914 was a slight shock, lasting about three seconds, felt at Walterboro, Colleton county, on May 31st, at 11:03 p.m. According to one observer the motion was apparently west to east. The barometric gradient sloped southeast. This shock was not recorded at Charleston or Summerville. Walterboro is only thirty miles S. 70° W. of Summerville, and the fact that the disturbance was not reported at the latter place is possibly due to the lateness of the hour, though it is not improbable that the origin was somewhat farther to the southwest than usual.

The next earthquake was recorded at Summerville, June 19th, at 3:13 a.m., with an intensity of about III. The barometric gradient sloped southeast, the sea-level barometric pressure at Charleston being

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[1] Seismic Activity in the Atlantic Coastal Plain, Near Charleston, South Carolina, *Bulletin Seismological Society of America,* 4, 109-160.

0.04 inch lower than that at Columbia, one hundred miles farther inland. An earthquake having an intensity of IV occurred July 13th, at 8:53 p.m., and was followed on July 14th, at 3:00 a.m., by a shock with an intensity between I and II. The barometric gradient on both days sloped northwest.

On September 22d, at 2:04 a.m., the heaviest earthquake shock of the year was felt. The estimated intensity was about V at Summerville, the town nearest the origin, and IV at Charleston; while at Columbia, Lexington and Augusta, seventy to eighty miles distant, the intensity was III. Macon, Ga., one hundred and fifty miles west of Summerville, was the most distant point reporting the shock. The area affected was not less than thirty thousand square miles, and probably was much greater. It is not possible to determine this area with any degree of accuracy, for, because of the early hour, the earthquake was reported from comparatively few towns. The barometric gradient on the morning of the earthquake sloped southeast. At Summerville the shock is reported to have been accompanied and slightly preceded by a noise like a train approaching from a distance. A few pictures were displaced on walls, but no damage resulted from the disturbance.

The last earthquake of the year was recorded at Summerville on December 23d, at 6:55 a.m., and had a low intensity, probably less than II. The barometric gradient again sloped southeast.

While, of course, it is not possible to draw general conclusions from data extending over such a short interval of time, it is interesting to note that the earthquakes which occurred during 1914 tend to strengthen conclusions already reached as a result of a study of the period from 1886 to 1913. In the paper on seismic activity near Charleston, referred to above, evidence was given in proof of the theory that most of these shocks are due to adjustments taking place along a northeast-southwest fault in the crystalline rocks underlying the Coastal Plain formations, and among other conclusions stated were the following:

"6. Any factor increasing the relative pressure on the northwest side of the assumed fault, or decreasing it on the southeast side, tends to increase the slowly accumulating stresses that result in readjustments with their accompanying earthquake shocks. While such factors may control the time of seismic disturbances, they are not to be regarded as causes.

"7. The most important factors affecting the relative pressure on opposite sides of the fault, and thus controlling the earthquake frequency, are rainfall, height of water-table, and barometric pressure."[2]

Four of the six earthquakes occurring in the Charleston area during 1914 took place when the barometric gradient sloped southeast; that is to say, when the atmospheric pressure was greater on the northwest side of the fault.

The total rainfall for the year was 44.32 inches at Charleston and 51.78 at Summerville, while for the year 1913 the figures were 41.49 and 45.15 inches respectively.[3] There was therefore an increase in the total amount of rainfall, and the excess of rainfall at Summerville over that at Charleston increased from 3.66 inches in 1913 to 6.46 inches in 1914. Since Summerville and Charleston are on opposite sides of the fault, this means that the effect of rainfall during 1914 as compared with 1913 was to increase the surface pressure on the northwest side of the fault relative to the southeast side.

The mean temperature for the year was 64.91° F. at Charleston and 63.89° at Summerville, making the difference in temperature 1.02°. In 1913 the mean temperature at Charleston was 66.4° and at Summerville 65.5°, making the difference 0.9°. There was therefore a slight increase in the difference in temperature, and since the height of the water-table in this section is very largely controlled by the precipitation and the evaporation, which varies with the temperature, it is probable that the surface pressure due to the height of the water-table was relatively greater on the northwest side of the fault during 1914 than it was during 1913.

The facts here stated, when considered in connection with the increase in seismic activity during 1914, certainly support the conclusions quoted above; and when the new data are plotted on the yearly rainfall, temperature and earthquake graphs, shown on Plate 8, Vol. IV of the *Bulletin of the Seismological Society of America*, the close relation between the curves, commented on in the previous paper, is seen to continue through the year 1914.

In addition to the six earthquakes recorded in the Coastal Plain, two were reported during the year in the Piedmont section of the state. A slight tremor was felt at Chester, March 6th, at 3:30 p.m., but does not seem to have been noticed at any other place. The other shock occurred at 8:20 p.m. of the same day and was reported from Florence, Hartsville and Darlington. The origin was probably between Hartsville and Darlington, and not far from the latter place. At Darlington the intensity was about IV, R.-F., and the disturbance is said to have lasted nearly one minute. At Hartsville the shock was preceded and accompanied by a deep rumbling sound, causing windows to rattle. At Florence the intensity appears to have been not more than II or III, R.-F.

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[2] Ibid., p. 148.

[3] The rainfall and temperature data used in this paper were compiled from "Climatological Data, South Carolina Section," by Richard H. Sullivan, Section Director, U. S. Weather Bureau.

The Georgia earthquake occurred March 5th, at 3:05 p.m., Central Standard Time. The origin was located about thirty miles southeast of Atlanta, Ga., where the intensity was VI.[4] The shock was felt in the western Piedmont section of South Carolina, being reported as far east as Cherokee county. It was also felt in parts of Alabama, Tennessee and North Carolina.

LIST OF SOUTH CAROLINA EARTHQUAKES DURING 1914.

Date	Time	Intensity	Remarks
March 6	3:30 p.m.	II or III	Reported from Chester.
March 6	8:20 p.m.	IV	Reported from Darlington, Hartsville and Florence.
May 31	11:03 p.m.	III	Reported from Walterboro.
June 19	3:13 a.m.	III	Reported from Summerville.
July 13	8:53 p.m.	IV	Reported from Summerville.
July 14	3:00 a.m.	II	Reported from Summerville.
Sept. 22	2:04 a.m.	V	Reported from Summerville, Charleston, Columbia, Augusta and other places.
Dec. 23	6:55 a.m.	II	Reported from Summerville.

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[4] Personal communication from Dr. Harry Fielding Reid, January 14, 1915.

University of South Carolina,
Columbia, South Carolina,
March 22, 1915.

AREQUIPA EARTHQUAKES REGISTERED DURING THE YEAR 1914

By LEON CAMPBELL
Arequipa Station of the Harvard College Observatory.
Communicated by the Director, EDWARD C. PICKERING.

From a seismological standpoint, the year 1914 was not so interesting, or exciting, in Arequipa as the previous year, although the total number of tremors registered was about the same.

Unfortunately, reliable observations of earthquakes felt in the city proper could not be obtained, due to the prolonged illness of Mr. Brett who had been so keenly interested in noting the disturbances during the year 1913. However, there is a prospect that he will be able to continue to record the observations of those felt in the city during the present year, for comparison with those made at the Observatory.

Reports of the tremors felt here have been regularly contributed to the Seismological Station of San Calixto, at La Paz, Bolivia, and the receipt of similar data from that station has proved most valuable in the study of those felt here.

In Table I is given a list of the earthquakes as registered at this Observatory during the year under discussion. Column 1 contains the current number assigned to each earthquake, consecutively, while columns 2 and 3 give the date and time of each shock. Column 4 contains the observed intensities, as estimated on the Rossi-Forel scale. The last column contains remarks made at the time of observation, or from subsequent knowledge which came to hand.

The discussion of the seismic activity in Arequipa has been made in the same manner as during the previous year, and these values are given in Table II, in which column 1 contains the including dates of each half month, while columns 2 and 3 give the sum total of the earthquakes in that interval of time and the sum of the intensities of the same, and column 4 contains the mean intensity for the corresponding intervals.

The strongest earthquake of the year occurred just before midnight of February 25th and caused considerable alarm among the pop-

TABLE I
AREQUIPA EARTHQUAKES DURING THE YEAR 1914.

No.	Date 1914	75th Mer. Time H.M.S.	Inten.	Remarks
1	Jan. 4	4:02 p.m.	II	Slight rumble, and jolt felt.
2	Jan. 7	2:50 a.m.	III	Duration 40 secs.
3	Jan. 18	9:50:45 p.m.	IV	Duration 20 secs.
4	Feb. 1	11:38:55 p.m.	III	Double shock. First, duration 3 secs. Second, 15 secs later, lasting 5 secs.
5	Feb. 6	9:35:50 a.m.	III	Duration 3 secs. Mark on plate decidedly lengthened to the NE by almost 10 mm.
6	Feb. 17	5:11:02 a.m.	V	Duration 30 secs. Strong enough to awaken people. Mark on plate 5 mm. to NE.
7	Feb. 25	11:58:51 p.m.	VI-VII	A strong shock; enough to awaken everybody. Duration 30 secs., followed some 5 secs. later (11:59:26) by a still stronger shock lasting a full minute, causing a general exodus from the house. Mark on plate extensive in a NE to SW direction, measuring 1.5 inches long by 0.75 inch wide. A clock pendulum, swinging in a N-S direction, found stopped.
8	Feb. 27	4:26:30 a.m.	II-III	Duration 4 secs.
9	Mar. 7	2:32 a.m.	II	Slight jolt to house.
10	Mar. 21	8:19:43 p.m.	II-III	Slight shock.
11	Mar. 22	8:11:40 p.m.	II	
12	Mar. 23	5:45 p.m.	I	
13	Mar. 23	10:51:15 p.m.	I	
14	Mar. 24	7:31:15 p.m.	I	
15	Mar. 25	7:50 a.m.	I	
16	Mar. 25	1:56:20 p.m.	I	
17	May 2	4:18:57 p.m.	IV	Duration 30 secs.
18	May 3	8:13:37 a.m.	I	
19	May 4	4:9:18:04 a.m.	II	
20	May 5	12:38:00 a.m.	III	Duration 18 secs.
21	May 17	2:29:20 a.m.	II	
22	June 8	9:19:24 a.m.	III	Short duration and sudden jolt.
23	June 13	12:29:37 p.m.	III	
24	June 16	5:04:20 p.m.	III	
25	June 22	4:01:02 p.m.	IV-V	Strong rumble heard, duration of quake 20 secs.

No.	Date 1914	75th Mer. Time H.M.S.	Inten.	Remarks
26	June 22	8:59:02 p.m.	IV	Felt as a double shock, duration 15 secs.
27	July 10	9:22:48 p.m.	II	
28	July 14	12:06:57 p.m.	I-II	
29	July 22	7:21:38 a.m.	III	Duration 5 secs.
30	Aug. 7	7:00:35 a.m.	III-IV	Duration .. secs.
31	Aug. 10	9:24 p.m.	III	
32	Aug. 12	3:32 p.m.	I-II	
33	Aug. 15	11:10:45 a.m.	II	
34	Sept. 4	1:45:57 p.m.	III	Duration 20 secs.
35	Sept. 11	12:39 a.m.	II	Duration 2 or 3 secs.
36	Sept. 11	6:47:07 a.m.	V	Duration 60 secs. Series of shocks. Marks on plate longest in ENE-WSW direction. Clouds of dust seen rising from pampa at foot of mountains.
37	Sept. 17	11:11:43 p.m.	III-IV	Duration 7 secs. Rumble heard like distant thunder.
38	Sept. 23	8:11 a.m.	III	Duration 5 secs.
39	Sept. 28	2:23 p.m.	I	
40	Oct. 6	12:17 a.m.	I	
41	Oct. 12	6:57:28 a.m.	III-IV	Reached climax at 6:57:45 a.m.
42	Oct. 23	9:14:19 a.m.	II	
43	Oct. 23	11:44 p.m.	III	Duration 5 secs.
44	Oct. 25	3:20 a.m.	II-III	Reported in town only.
45	Oct. 25	3:48 a.m.	III	
46	Oct. 26	10:52:45 p.m.	IV	Duration 20 secs.
47	Nov. 17	9:32:56 a.m.	II-III	
48	Nov. 19	7:36 a.m.	II	
49	Nov. 21	11:44:54 a.m.	III	A heavy jolt felt; quake lasted 3 secs.
50	Nov. 23	11:27 p.m.	I-II	
51	Dec. 2	6:56:12 p.m.	III	Duration 10 secs.
52	Dec. 2	7:08:11 p.m.	III-IV	Duration 3 min. Seismograph seen to move for this length of time, according to H. P., observer.
53	Dec. 5	12:04:20 p.m.	I	
54	Dec. 6	6:50 a.m.	III	Duration 2 min., more or less.

ulace. It was even more severe to the west and south of Arequipa, reaching into the northern part of Chile. For a distance of some thirty miles inland from the coast at Mollendo, the heavy roaring and surging of the ocean could be heard following closely upon the move-

TABLE II

TABLE OF SEISMIC ACTIVITY IN AREQUIPA, 1914.

Dates 1914		No. of Earthquakes	Sum of Intensities	Mean Intensities
January	1 - 15	2	5.0	2.5
	16 - 31	1	4.0	4.0
February	1 - 14	2	6.0	3.0
	15 - 28	3	14.0	4.7
March	1 - 15	1	2.0	2.0
	16 - 31	7	9.5	1.3
April	1 - 15	0	0.0	0.0
	16 - 30	0	0.0	0.0
May	1 - 15	4	10.0	2.5
	16 - 31	1	2.0	2.0
June	1 - 15	2	6.0	3.0
	16 - 30	3	11.5	3.8
July	1 - 15	2	3.5	1.8
	16 - 31	1	3.0	3.0
August	1 - 15	4	10.0	2.5
	16 - 31	0	0.0	0.0
September	1 - 15	3	10.0	3.3
	16 - 30	3	7.5	2.5
October	1 - 15	2	4.5	2.2
	16 - 31	5	14.5	2.9
November	1 - 15	0	0.0	0.0
	16 - 30	4	9.0	2.2
December	1 - 15	4	10.5	2.6
	16 - 31	0	0.0	0.0
	Total	54	142.5	2.6

ment of the earth. To the north and east it was scarcely felt at all. The epicenter appears to have been due south of Mollendo, probably out to sea.

The two earthquakes which occurred on the second of December, in the early evening, although not so strongly felt in Arequipa, were quite severe to the west. The epicenters of both of these disturbances appear to have been very near to that of the terramoto of August 6, 1913, which caused so much damage in Chuquibamba and Caraveli. The earthquake of September 11th was also quite severe in Caraveli, but not so bad as was reported, at the time, in the newspapers.

From the above it would seem that, due to the frequency of tremors on the Pacific Coast at about 16° south latitude, a more detailed study of the earthquakes in that region would be certainly worth while, for that locality may be the center of more disturbances to come.

From a preliminary examination of the data published at the San Calixto Station the preponderance of tremors as registered there, within a radius of one thousand kilometers, appears to emanate from, or near, longitude 73° west and latitude 15.5° south. This fact tends to confirm the above statement, that the last mentioned place is the center of numerous tremors and should be more carefully investigated.

"*O*" AS A SYMBOL FOR TIME AT ORIGIN

By J. B. Woodworth

Wiechert's now universally adopted "International Nomenclature," including the phase symbols *P, S, L, C, F,* and combinations expressing the reflection of waves, appears to lack in common with earlier systems one important character, that for the initial phase of all these waves, the time at origin. The time at origin in teleseismic observations is a matter of inference and calculation based upon constants giving the speed of propagation of seismic vibrations. The registration of time at origin possibly is attained in certain shallow shocks arising beneath an earthquake station; but this event rarely happens. The close approximation to the probably exact second of time at which many shocks occur, which is now attainable by the aid of corrected tables for the time of transit, makes it desirable to employ a symbol, correlative with those of the instrumentally registered phases, for the inferred initial impulse of distant earthquakes. Such initial phase would be understood of course to mean that phase of a possibly prolonged shock whose intensity rose to the point at which vibrations were sent outward to great distances. In most earthquakes of high intensity this phase is probably from the nature of the cause of the shock an initial movement.

For the time at origin some German bulletins have used the letters *HZ* (Herdzeit). Other writers have employed *t* with subscripts to indicate different determinations of the time at origin based upon the intervals *S-P* and *S-eL,* etc.; but *t* as a character is associated with *T,* carrying the idea of a *period* of time. *HZ* does not naturally lend itself to international use. It has seemed to the writer, therefore, that seismologists might without risk of ambiguity adopt *O,* the symbol for the origin of coordinates in Des Cartes' famous system published in his *Discours* in 1637, where *O* designates the locus of a point rather than a time; but in seismology the time of the initial phase and the axis of the theoretical epicenter are coincident terms. *O* in the sense of point of origin may lie some kilometers beneath the epicenter, and hence would connote the origin and not epicenter. *O* followed by the time in h. m. s. would not be mistaken for *O* followed by λ and φ with appropriate values to designate the epicenter, should it be desirable to employ O in both senses. The epicenter may be written O^z, borrowing z (for zenith) the vertically upward component in the xyz coordinates of Cartesian geometry.

The symbol O becomes convenient in writing the transit equations; *e. g.*, $P - O$ (read P minus O) = 6m 10s; $S - O$ = 12m 40s; and correspondingly O based on $S - P$ may be written O'; O based on $eL - S$ may be written O''; O based on $eL - P$ may be written O'''; or significant subscript letters may be affixed.

The determination of O = time at origin, might well be issued in bulletins giving earthquakes phases, printing O and its h. m. s. values in italics, on the line of the date, to indicate that it is a deduction from the *observed* times of the phases which follow. O thus given on the basis of known tables for transit times becomes at once an index of the accuracy of the observed phases, and enables the reader of a set of bulletins to compare the reports of the same earthquake, since with accurate data O should be a time common to all of them. Furthermore, since time is equivalent to terrestrial longitude, discrepancies in O between different observatories indicate the error in longitude which will arise in using the data in the location of the epicenter. By taking the mean of O for a group of records the center of gravity of the triangle of error may be arrived at, and by adding algebraically corrections to the distance (or to $P - O$, etc.) of the records departing from the mean O, the determination of the epicenter may proceed without further correction.

The attempt to obtain O correctly should result in the improvement of seismographic reports, which from various causes, apparently not all unavoidable, display great divergences. The symbol is being used this year in the Harvard bulletin whenever the data permit the reduction of the phases to their time of starting out from the point of origin.

Harvard University, Cambridge, Mass.

SEISMOGRAPHS AT THE PANAMA-PACIFIC EXPOSITION

By S. D. Townley

There are two exhibits of seismographs at the Exposition. In the Japanese exhibit, in the Liberal Arts Building, two seismographs are shown. The one is Omori's horizontal pendulum tromometer, which has a magnification of 200, and is used for recording slight and unfelt seismic movements, and also pulsatory oscillations of the ground. The second is Tanakadate's strong-motion seismograph, which "records the horizontal and vertical components of the motion of the ground in a great or destructive earthquake. The instrument is put in motion automatically and only in case of such a shock."

The Japanese exhibit also contains large reproductions of seismograms, publications of the Imperial Earthquake Investigation Committee, and many large photographs of earthquake damage, and volcanic eruptions, notably those of Asama-yama in 1912 and Sakura-jima in 1914.

The second exhibit consists of a Bosch-Omori seismograph shown by the U. S. Weather Bureau in its exhibit in the Agricultural Building.

MEETING OF THE SEISMOLOGICAL SOCIETY

There will be a meeting of the Seismological Society of America in Berkeley at the time of the meeting of the American Association for the Advancement of Science, August 2-7, 1915. A program is now being arranged and will include an address by President McAdie. Members having papers to present should send titles to the Secretary as soon as possible.

SEISMOLOGICAL NOTES

Continued activity of Lassen Peak, California.—The recent volcanic activity of Lassen Peak in Shasta county, California, was described in detail by Dr. Diller in an article published in this journal, volume IV, no. 3, at pages 103 to 107. During the months of April and May 1915 the newspapers have published notices of various explosions. The following have come to our attention:

April 9th ashes were thrown from two separate craters for about ten minutes, and drifted northward at a height of about a thousand feet.

April 15th an eruption of ashes lasted more than half an hour.

Three or four explosions occurred on April 16th.

April 27th there was a pronounced explosion, and ashes from it were carried as far as Cottonwood, which is fifty miles distant, and to Anderson, which is six miles north of Cottonwood.

There was another explosion on May 14th at midnight.

On May 19th it was reported, on apparently trustworthy authority, that molten lava was flowing down the western slope of the peak.

Another eruption shortly after midnight on May 21st caused a flood of mud to rush down Hat Creek valley, in the eastern part of Shasta county, burying farm lands at places to a depth of three feet.

Another eruption occurred on May 23d, causing another flood of mud in Hat Creek valley. The floods in Hat Creek valley seem to have been caused by the melting of snow by the heat from the eruptions, thus carrying down large quantities of volcanic ash previously deposited. Heavy rains also occurred, and it may be that these were the chief factor in causing the floods.

The Forestry Bureau's service station is said to have been destroyed by a rock that fell upon it. Much standing timber has also been destroyed.

Still another large eruption occurred on May 30th, just one year after the first activity shown by the volcano.

Port of Spain, March 26, 1915.—Mr. George A. Macready kindly sends us a note of a shock felt at 12:02 a.m. on March 26th at Port of Spain, Trinidad, British West Indies. He thinks it may have lasted three seconds. No chimneys were damaged, but some plaster fell from the walls of old buildings. Most people were awakened, but there was no panic. Some clocks were stopped.

Perugia, Italy, March 27, 1915.—Several shocks were felt in the province of Perugia, but though no damage was done the people moved out and camped in the open. There was evidently some nervousness on account of the late fatal earthquakes in the Abruzzi provinces.

San Jose, California, March 31, 1915.—Prof. F. J. Rogers of Stanford University noted a shock at San Jose at 4:33 a.m. P. S. T. It lasted only about two seconds and had an intensity of between II and III, R.-F. scale. The shock was felt by many persons.

Avezzano district, Italy, April 5, 1915.—After the disastrous earthquake of January 13, 1915, shocks were of almost daily occurrence for months in that part of Italy. On April 5th, however, there was another violent quake in the Avezzano district, and also at Reita, and a gentler one at Rome where it occurred at 7:20 a.m. At Tagliacozzo several houses were damaged.

Sassnolo, Italy, April 5, 1915.—A sharp shock was reported at Sassnolo, sixty miles north of Florence, at 7:40 a.m. No damage was done.

San Luis Obispo, California, April 21, 1915.—Mr. R. E. Collom reports a shock at San Luis Obispo at 1:57 a.m., with an intensity of IV to V, R.-F. scale. No damage was done.

Tacoma and Seattle, Washington.—A shock was felt at Tacoma, Washington, at 10:37 a.m., April 22, 1915. It was also felt at South Tacoma and at Dupont, fourteen miles to the west, and in the Puyallup valley. It was recorded by the seismograph of the University of Washington at Seattle at 10:34.

Tagliacozzo, Italy.—On April 24th a strong shock was felt at four o'clock p.m. and lasted several seconds. It caused great alarm. The epicenter seems to have been at or near Tagliacozzo, where several houses were damaged, and some tottering walls fell.

Tiptonville, Tennessee.—On April 29, 1915, an earthquake occurred at Tiptonville, Tennessee, between five and six o'clock p.m. Some alarm was caused, but no damage was done.

Central California, May 28th.—A light earthquake at about 10:50 p.m. was reported from Fresno, Porterville, Merced and Bakersfield. It seemed to be heaviest at the last-named place.

A letter concerning this earthquake has been received from Mr. F. W. Warthorst of Bakersfield. He was not awakened, but judging by reports of others Mr. Warthorst estimates the intensity as V, R.-F. scale. Windows rattled, pictures and electric lights moved, but there was no damage whatever to buildings.

ADDENDUM

Mr. Wood has sent the following addition to his article on "The Seismic Prelude to the 1914 Eruption of Mauna Loa," volume 5, page 48, after line 5:

1892, Dec. 1—Action at summit, 3 days only.
No flow.
No earthquakes recorded.

REVIEWS

Dr. E. Tams.—UEBER DIE FREQUENZ DER NACHSTÖSSE STARKER BEBEN. (On the Frequency of After-Shocks of Severe Earthquakes.) *Die Naturwissenschaften,* Heft 11, 145-150, 1915.

Although the after-shocks of severe earthquakes repeat themselves with continually decreasing frequency and intensity, it is out of the question to speak of regular decrease, except in the most general sense.

The studies of F. Omori on the earthquakes of Japan have thrown much light on this question. The earthquake of the 28th of October 1891, which caused great destruction in central Nippon, was followed, in the course of the next two years, by 3365 after-shocks, registered at Gifu. The Hokkaido earthquake of March 22, 1894, registered in Nemuro, was followed by 663 after-shocks up to the end of December 1894.

Omori has deduced from these and similar cases the following formula: $y = \frac{a}{x + b}$, in which x is the time, y the number of after-shocks, and a and b are two constants to be determined from actual observations of x and y, by the method of least squares.

Kövesligethy[1] has used this principle in a study of a theoretical basis of the prediction of earthquakes; and S. Kusakabe[2] has attempted to deduce this formula from actual observations and conjectures concerning the elastic conditions after the shock.

Kusakabe expresses the law of the frequency of the after-shocks in this modification of the formula:

$$y = \frac{c}{x + d} - \frac{c}{T} \log \left(1 + \frac{T}{x + d}\right),$$

in which c and d depend on the elastic condition of the earth's crust and the length of time of observation; T is the time of accumulation of the force that caused the principal shock, and log is the natural logarithm. T, in the case of tectonic earthquakes, is to be assumed as very great.

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[1] *Math. und Nat. Berichte aus Ungarn,* 26, 212, 1910.

[2] *Journal of the College of Science,* Japan, 21, 1 et seq., 1906-1907.

For the California earthquake of 1906, H. F. Reid has set this time as one hundred years.

Tested in the light of other earthquakes, the equation of Omori shows only a restricted value. The observations on the Ligurian earthquake of the 23rd of February 1887, and of the Calabrian earthquake of December 28, 1908, by no means agree with it.

One must take into account not only the frequency of the after-shocks, but also their intensity, and so deduce instead of a frequency-curve an activity-curve. The California earthquake is particularly suitable for this deduction, for the records of the after-shocks show that the curve is not even approximately hyperbolic. One sees here, as in other earthquakes, a rapid decrease, but the activity shows very strongly marked variation. The stronger after-shocks start a new series of minor quakes, and thus tend to increase the activity record.

The work of F. Wähner[3] on the earthquake of Agram of November 9, 1880, shows the same irregularly decreasing intensity, and teaches that neither the maximum of frequency nor that of activity necessarily follow directly after the principal shock. Taken along with the curve of the records of the California earthquake, this shows that the occurrence of the after-shocks in each case is governed by uncertain factors, and that one may speak only in very general terms of a more rapid decrease in the beginning and of a later more gradual decrease in frequency and activity. In order to give these curves greater value it would be necessary to know not only the regional distribution of the shocks, but also their *absolute* intensity, the position of the epicentrum, and the depth of the origin.

The records of the great Indian earthquake of April 4, 1905, also show clearly the influence of strong after-shocks, in that the curve is not even approximately hyperbolic.

J. P. SMITH.

IL RECENTE TERREMOTO NELLA MARSICA E GLI STRUMENTI SISMICI, by G. Agamenone. *Rendiconti della R. Accademia dei Lincei,* Classe di scienze fisiche, matematiche e naturali, vol. XXIV, serie 5^a, 1° sem., fasc. 3°. Seduta del 7 febbraio, 1915.

The author concludes that the epicenter of the earthquake of January 13, 1915, was near the southern slope of Mount Velino. The damage done in the valley of the Liri makes him think that either there were two seismic centers which entered into action at practically the same time or the epicenter had a linear form and for geological reasons caused the greatest damage in two far distant points.

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[3] *Sitzungsber. d. K. Akad. Wiss.,* Wien (Math.-Nat. Classe), **88**, 255 et seq., 1882.

He then asks at which of the two points the movement began. Of the observatories at Montecassino, at Rocca di Papa, and at Rome, the shock was felt earliest at the observatory at Montecassino. Accordingly this observatory must have been nearer to the original shock than were the other two, and the movement must have begun in the valley of the Liri.

He notes the remarkable number of secondary shocks recorded by the seismograph at Rocca di Papa. The instrument was out of action from 7:53 to 8:37 a.m. From then until midnight it registered 240 shocks, and, on the following days, 120, 88, 38, and 30 shocks, successively. Up to February 6th, 750 shocks were registered, and doubtless other smaller shocks were lost because of the microseismic agitation which always affects the instrument. Only a few of these shocks were perceptible to the senses.

The author then undertakes to compute the surface velocity of the seismic waves. He assumes for the time being that Avezzano was the epicenter of the shocks. He computes, from the time when it was felt at Montecassino, at Rocca di Papa, and at Rome, the time when it was first felt here. Then, taking the time at which it was felt at twenty observatories both in and outside of Italy, and the distance of these observatories from Avezzano, he finds that the average velocity was 7330 meters per second. Rejecting seven of the observations because they seem unreliable, the average velocity for the remaining thirteen is 7690 meters per second, varying between 6960 meters for Padua and 8950 meters for Treviso.

The author appends a portion of a seismogram traced in the seismological station at the Cartuja in Granada.

C. G. ALLEN.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Harvard University, Cambridge, Mass.—Records of the Seismographic Station, nos. 5, 5*a*, and 7, March 1 to April 30, 1915.

Ottawa, Canada, Earthquake Station, Dominion Astronomical Observatory.—Reports nos. 3 and 4, March 1 to April 30, 1915.

ASIA

Zi-Ka-Wei, China.—Bulletin Sismique, nos. 13, 14, and 14 bis, October 23 to December 28, 1914; also nos. 1 and 1 bis, January 1 to February 28, 1915.

EUROPE

Boletín Mensual de la Estación Sismológica de Cartuja (Granada), nos. 11 and 12, October to December, 1914; also nos. 1-3, January-March 1915.

Mitteilungen des Zentralbureaus der Internationalen Seismologischen Assoziation, nos. 2 to 5, pp. 13-125, 1913 to 1914.

Mitteilungen der Hauptstation für Erdbebenforschung am Physikalischen Staatslaboratorium zu Hamburg, nos. 1-3, January to March 1913; nos. 1 to 5, August to December, 1914; and no. 1, January 1915.

Stonyhurst College Observatory.—Earthquake records by Milne seismograph, January 1 to March 26, 1915.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological bulletins of the Observatory, nos. 29 to 36, October 1 to December 31, 1914; also nos. 1 to 3, January 1 to 31, 1915.

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS OF THE SEISMOLOGICAL SOCIETY OF AMERICA

MAY 3, 1915

The meeting was called to order at 4:30 p.m. by Vice-President Tolman, in Room 66, Stanford University. Directors Arnold, Durand, Taff, Tolman and Townley were present.

The minutes of the meeting of the Board held on January 20, 1915, were read and approved.

The report of the Board of Election was read by the Secretary.

After being duly nominated the following officers were elected for the year:

President	A. G. McAdie
First Vice-President	J. B. Woodworth
Second Vice-President	C. F. Tolman, Jr.
Third Vice-President	Ralph Arnold
Secretary-Treasurer	S. D. Townley

The report of the secretary-treasurer for the year ending April 3, 1915, was read and ordered filed.

The report of the auditing committee was read by Director Durand and ordered filed.

Mr. E. M. Keyser, of San Francisco, Cal., was elected to membership in the Society, and the Libraries of the University of Oregon and the University of Washington were added to the list of subscribers. The loss of six members through resignation was reported by the secretary.

A letter from A. L. Barrows concerning exhibits of seismographs at the Panama-Pacific Exposition was read, and the Secretary was instructed to cooperate in the matter.

The salary of the Secretary-Treasurer was continued for one year at the rate of $20.00 per month.

Adjourned at 5:45.

S. D. Townley, *Secretary.*

REPORT OF THE BOARD OF ELECTION

The annual election of directors of the Seismological Society of America was held in Room 752, Phelan Building, San Francisco, Cal., on April 3, 1915.

The report of the Board of election is as follows:—

PRESIDENT AND MEMBERS OF THE SEISMOLOGICAL SOCIETY:

We, the undersigned judges of election, certify that 150 ballots were cast at the annual election, held in San Francisco on this date, with the following result. Two ballots were blanks.

Ralph Arnold	108	M. M. O'Shaughnessy	46
J. C. Branner	148	H. F. Reid	130
W. F. Durand	115	F. J. Rogers	55
J. C. Jones	40	Stephen Taber	49
A. C. Lawson	136	J. A. Taff	67
A. O. Leuschner	59	C. F. Tolman, Jr.	118
A. G. McAdie	119	S. D. Townley	134
C. F. Marvin	117	Otto von Geldern	87
R. B. Moran	45	J. B. Woodworth	113
G. D. Louderback	1	H. F. Bain	1

The following named, being the twelve receiving the highest number of votes, are declared elected Directors of the Society for the year 1915-16: J. C. Branner, A. C. Lawson, S. D. Townley, H. F. Reid, A. G. McAdie, C. F. Tolman, Jr., C. F. Marvin, W. F. Durand, J. B. Woodworth, Ralph Arnold, Otto von Geldern, J. A. Taff.

D. S. RICHARDSON,
LUTHER WAGONER,
E. F. DAVIS,
H. W. TURNER,
Board of Election.

April 3, 1915.

REPORT OF SECRETARY-TREASURER

From April 4, 1914, to April 3, 1915.

The total number of members of the Society and subscribers to the BULLETIN is now 414, a decrease of 13 during the year. Three members were lost through death, Mr. W. R. Eckart of Palo Alto, Cal., Mr. Beach Thompson of Menlo Park, Cal., and Professor N. H. Winchell of Minneapolis, Minn.

Volume 4 of the BULLETIN, containing 247 pages and 9 plates, was issued during 1914.

The financial report is as follows:—

GENERAL FUND

Dr.	
To balance, April 4, 1914	$ 61.08
Dues and subscriptions	733.35
Reprints	11.70
Sale of publications	4.00
Transfer from Sayles Fund, interest	267.89
Transfer from Sayles Fund, principal	200.00
Transfer from Life Membership Fund, interest	16.25
Total	$1,294.27
Cr.	
By Stanford University Press, printing Volume 4	$ 753.45
Stanford University Press, reprints	68.25
Stanford University Press, miscellaneous printing	38.75
Commercial Art Co., illustrations	55.82
Second-class postage on BULLETINS	6.56
Foreign postage on BULLETINS	9.77
Miscellaneous postage	14.50
Stamped envelopes	21.24
Rent of safe-deposit box	2.00
Salary of Secretary-Treasurer	240.00
Balance, April 3, 1915	83.93
Total	$1,294.27

LIFE MEMBERSHIP FUND

Dr.	
To balance April 4, 1914	$ 400.00
One life membership (transfer from Sayles Fund)	25.00
Interest from Berkeley Bank of Savings and Trust Co.	16.25
Total	$ 441.25

Cr.

By interest, transferred to General Fund	$ 16.25
Balance, April 3, 1915	425.00
Total	$ 441.25

SAYLES FUND

Dr.

To balance, April 4, 1914	$4,700.00
Interest from Mutual Building and Loan Association of San Jose and College Park	60.00
Interest from Palo Alto Mutual Building and Loan Assn.	120.00
Interest from Truckee Lumber Co.	60.00
Interest from Bank of Palo Alto, Savings Department	27.89
Total	$4,967.89

Cr.

By transfer to General Fund, interest	$ 267.89
Transfer to General Fund, from Bank of Palo Alto, principal	200.00
Transfer to Life Membership Fund	25.00
Balance, April 3, 1915	4,475.00
Total	$4,967.89

S. D. TOWNLEY, *Secretary-Treasurer.*

REPORT OF THE AUDITING COMMITTEE.

San Francisco, April 16, 1915.

TO THE BOARD OF DIRECTORS OF THE SEISMOLOGICAL SOCIETY OF AMERICA:

Gentlemen:—

The undersigned committee beg to report that, in accordance with your instructions, they have examined the books and vouchers of the Secretary and Treasurer of the Society for the period from April 6, 1911, to April 3, 1915, and find as follows:

GENERAL FUND

The balance reported, $83.93, agrees with that of the commercial account carried with the Bank of Palo Alto.

All vouchers for disbursements have been checked and a proper receipt has been found for each entry.

Each entry for dues paid has been checked from the membership card. For the year 1911, these debits have been made in lump amounts, and it was found impossible to check each entry on the membership cards individually; but, by taking the total amount debited in the cash book for dues from April 6, 1911, to April 6, 1912, and adding together the number of entries made on membership cards for the same period, we are satisfied that the entries in the cash book correctly represent the credits on the membership cards.

Life Membership Fund

The amount received from Treasurer Joseph N. Le Conte, April 6, 1911, $258.35, agrees with the entry in the passbook of the Berkeley Bank of Savings.

Dividends and new payments have been properly entered, and the balance now shown by the Treasurer, $425.00, agrees with the balance shown on the passbook of the Berkeley Bank of Savings.

Sayles Fund

The condition of this fund is as follows:

Balance in Palo Alto Savings Bank	$ 475.00
Certificate No. 158, Palo Alto Building and Loan Association	1,000.00
Certificate No. 159, Palo Alto Building and Loan Association	1,000.00
Certificate Mutual Building and Loan Association	1,000.00
(These certificates all bear interest at the rate of 6% per annum.)	
Truckee Lumber Company first mortgage 6% gold bond	1,000.00

The balance in the Palo Alto Savings Bank, as shown by the Secretary's book, agrees with that actually in the hands of the bank. The certificates of stock and bond of the Truckee Lumber Company have been inspected by a member of the committee in the vaults of the Bank of Palo Alto, and have been found in order.

The cash book and records submitted to the committee have been found in excellent condition, and are believed to represent a correct and true statement of the Society's finances.

Respectfully submitted,

J. K. Moffitt,
W. F. Durand,
Otto von Geldern,
Auditing Committee.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

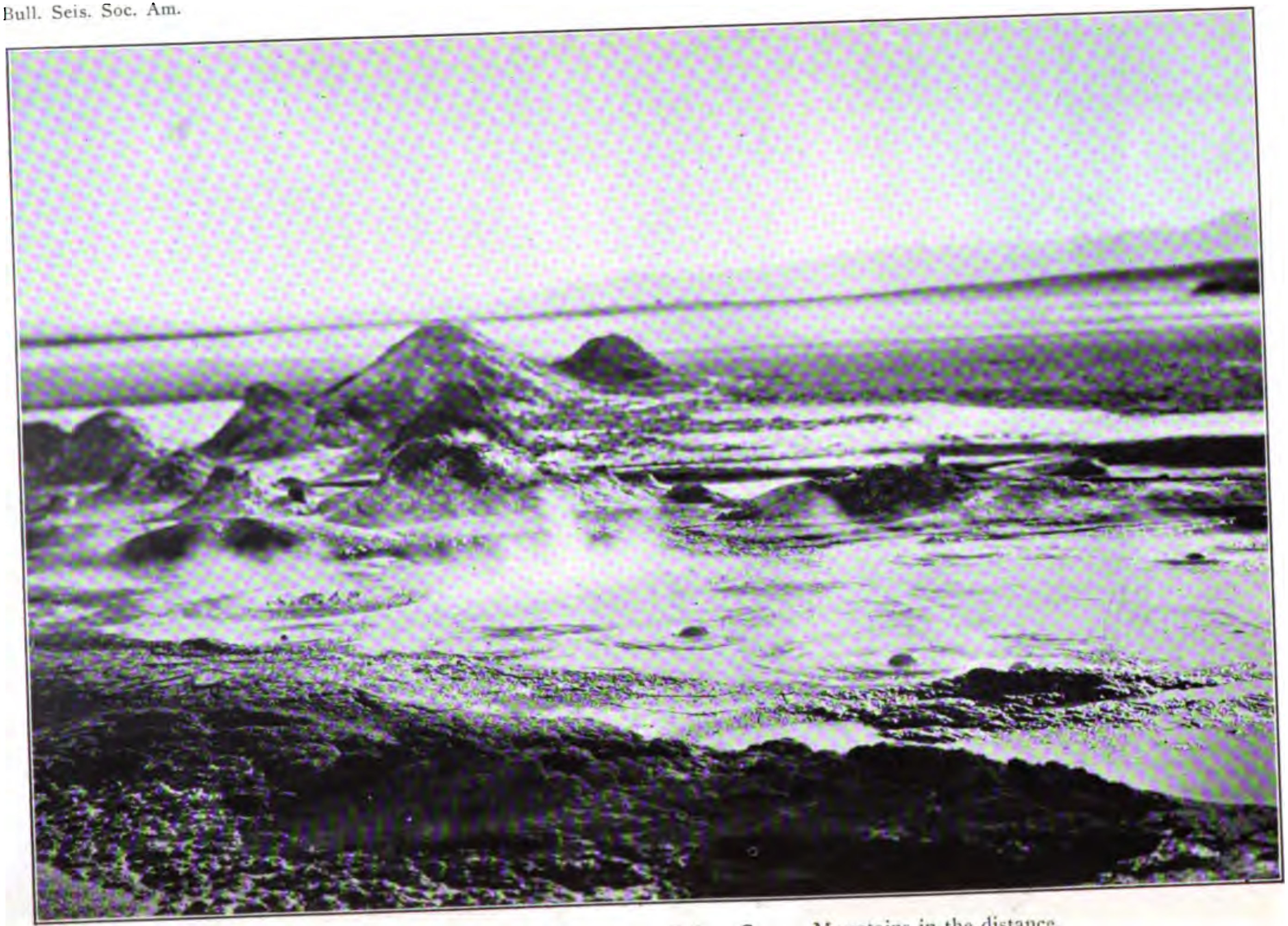
VI. **Fairly strong shock**: general awakening of those asleep, general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very strong shock**: fall of chimneys, cracks in walls of buildings.

IX. **Extremely strong shock**: partial or total destruction of some buildings.

X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.



Mud volcanoes on the west side of Volcano Lake. Cocopa Mountains in the distance.
Photograph by D. T. MacDougal.

The Bulletin of the
Seismological Society of America

VOL. V SEPTEMBER 1915 No. 3

PRESIDENT'S ADDRESS, MEETING OF THE SEISMOLOGICAL SOCIETY OF AMERICA, STANFORD UNIVERSITY, CAL., AUGUST 4, 1915.

By Alexander McAdie

Wednesday, April 18, 1906, about 5:12 a.m., a slip on the San Andreas fault produced horizontal displacements of several millimeters at San Francisco. The fault is about 435 kilometers long and the depth is about 20 kilometers. The average slip was about 4 meters near the fault line. The horizontal displacements on opposite sides of the fault ranged from one to five thousand millimeters.

If we accept the elastic rebound theory of the origin of earthquakes as set forth by H. F. Reid, we may picture an elastic strain, of a shearing nature, existing in this region, and when this strain exceeded the breaking point of the surface strata, there was a fracture and a quick springing back of the two blocks into a position of equilibrium. The degree of rebounding motion would be greatest near the break and practically be nil at a distance of ten kilometers. The vibrations and transmitted earth-waves which were picked up by seismographs, the world over, originated in the surface near the fault and traveled with the velocity of compressional earth-waves. The various seismograph records can be found in the Report of the Earthquake Commission published by the Carnegie Institution; but unfortunately of very limited distribution.

After the earthquake, certain careful geodetic measurements were made in this vicinity at the insistence of the first President of this Society, Professor George Davidson, and it was found that there had been a lengthening of the earth's surface between Mount Tamalpais and Black Mountain of about three meters. This, however, was the combined result of two memorable earthquakes, that of October 21, 1868, and April 16, 1906. To express this in popular terms we may say that the Golden Gate, which between these points is 79 kilometers wide, had been stretched an appreciable distance. The lengthening is about one part in twenty-six thousand. (See Coast and Geodetic Survey Report, 1907, Appendix 3. By Hayford and Baldwin.) It is reasonably certain then that our earthquakes are displacements of large area; during 1868, for example, a block of at least 700 square miles was moved or rotated about 1.5 meters in azimuth 168° (12° west of N.). In the earthquake of 1906, there was at the moment of rupture, according to Reid, work done of about 316354 x 10^6 kilowatts (130,000 million million foot-pounds, or roughly 236 x 10^9 horsepower). Of 520 monuments studied by Omori, the greatest number were overturned to the east or east slightly north. The mean direction of overturning was N. 76° E.

The 1868 disturbance occurred along what is known as the Haywards fault; and there is some evidence of increasing strain now along this line. The 1906 quake occurred, as has been stated, along the San Andreas fault. The intensities, so far as we can judge, were about the same and would be classified as VIII or IX on the Rossi-Forel scale. And this brings us at once to what is perhaps the most urgent matter this Society or any body of seismologists can consider at the present time, namely, the adoption and acceptance of an authentic intensity scale. The time has come when we must abandon the use of the Rossi-Forel scale, which, while arbitrary, was convenient. Today it is as much out of place as the Beaufort wind scale is in meteorology. This latter was devised at a time when all war vessels were sailing ships, and such an expression as "full and by" meant something definite as to a ship's headway. Except in official circles, where we regret to say there is a disposition to continue the use of such scales (see *Monthly Weather Review*, April, 1914, p. 26), both the Beaufort and the Rossi-Forel scales have become obsolete. And it is also time that we should discourage the further collection of reports of motion or direction when based only on personal impressions. Dr. Branner has, we think very properly, called attention (BULLETIN, SEISMOLOGICAL SOCIETY, March 1915, p. 28) to the untrustworthiness of such estimates, and quotes Montessus de Ballore's decision that such information regarding direction should be excluded hereafter from earthquake catalogs. I can not do better than repeat the fifth of Branner's conclusions in the article mentioned, as follows:

> "Instrumental records show that the directions are many and the movements complex. Out of such entangled movements, it seems quite impossible for our uncertain impressions to gather trustworthy conclusions regarding the location of epicenters."

Regarding a suitable scale of intensity, we think at once of the so-called absolute scale of Omori, where the intensity is proportional to the acceleration, or rather maximum acceleration, of the earth particles. It will be remembered that it is not velocity, but rate of change of speed, *i. e.*, acceleration, which is all-important in determining earthquake effect; and in the C. G. S. system this is expressed in centimeters (or millimeters) per-second-per-second. For most seismographic work the convenient unit is the milligal, or one-hundreth of a millimeter per-second-per-second. This is nearly one-millionth of the acceleration (normal) of gravity. The last syllable of the word is derived from the first part of Galileo's name. In the Omori scale there are seven divisions, ranging from the feeblest disturbance, where the maximum acceleration would not exceed 300 mm./sec.^{2}, to the most intense. Another dynamical scale, that of Cancani, suggested in 1904, has twelve divisions, with accelerations ranging from 2 mm./sec.^{2} to 10,000 mm./sec.^{2} As yet no scale has been generally adopted. It is fully realized that this matter belongs properly to the International Association of Seismology; but the European war (and no earthquake in history may compare in destructiveness with this mad work of man) has ruined all prospect of further international coöperation. Furthermore, the statutes of the International Seismological Association expire by limitation April 1, 1916. It is therefore advisable that this Society act in the matter.

It will not be thought presumptuous if your speaker offers tentatively the following intensity scale. Starting from a condition of rest, we might classify earthquakes on a scale of ten, thus:

1.	Acceleration	1-10	mm./sec^2.	Instrumental. Detected only by instruments.
2.	"	-25	"	Feeble
3.	"	-50	"	Slight.
4.	"	-100	"	Moderate.
5.	"	-250	"	Some damage.
6.	"	-500	"	Strong.
7.	"	-1000	"	Much damage.
8.	"	-2500	"	Disastrous.
9.	"	-5000	"	Catastrophic.
10.	"	-10000	"	Absolute ruin.

This scale is elastic enough to meet all requirements, and permits of emphasis on both slight and strong disturbances. Such a classification would be of great value in cataloging and studying earthquakes statistically. The same disturbance reported at different places would be readily recognizable, and entered intelligently as one and the same, instead of as at present loading and confusing all lists. It gives promise of satisfactory zonal values, and can be used in connection with areal intensities. Reid has proposed a method based upon the fact that the energy exerted is proportional to the square of the area within a given isoseismal.

We may also be pardoned for urging at this meeting the adoption of a single time-scale for the whole world. Presumably this would be Greenwich mean civil time, for use in all future catalogs and computations. Fortunately most seismographic observatories now use this time, or can with little trouble. And in connection with time, there is another desideratum which is of import not only in interpreting seismographic traces accurately, but also for catalogs and general study of earth movements. This is, the use of a suitable symbol for time at the origin. The suggestion is due to Woodworth (BULLETIN SEISMOLOGICAL SOCIETY, June, 1915, p. 105), who proposes "*O*" as an expressive symbol, pointing out that in seismology, the time of the initial phase and the axis of the theoretical epicenter are coincident terms. Since the origin lies below the epicenter this latter may be written "O^z," borrowing z for zenith distance or upward component from the co-ordinates of Cartesian geometry. He adds:

> "The attempt to obtain "*O*" correctly should result in the improvement of seismographic reports, which for various causes, apparently not altogether unavoidable, display great divergences."

The symbol is being used this year in the Harvard bulletin whenever the data permit the reduction of the phases to the time of starting out from the point of origin.

The Society might well discuss this suggestion.

Passing from the matter of scales of intensity and time, we come to another problem which the exigencies of the war havé brought about. This is the prompt publication of all determined epicenters. Of course this belongs to an International body, and we are not unmindful of what has been planned and to a small degree carried out. There is a catalog of earthquakes recorded in 1907, published at Strassburg in 1912 by Sziertes, and in which reports from 150 stations are considered. During that year, it will be recalled, there were many (96) world-shaking disturbances. We still await, however, the data for subsequent years, some of which perhaps may be ready for the press and delayed by the war. This Society might inquire, and our intention could not be misconstrued, concerning the disposition of this material and the prospect of publication. If it be found that the outlook for quick publication is unfavorable, we might attempt to secure publication in the BULLETIN or through other channels. In this connection it may be mentioned that Klotz at Ottawa has been publishing annually since 1911 such lists of epicenters as he could determine from data at his control. In his last list he says that owing to the absence of reports from Europe since July 1, 1914, the lists must be discontinued.

Would it not be wise if we should make united effort to obtain records from Alaska, the Aleutian, Hawaiian and Philippine Islands, Central and South America, Asia and Australia, centralizing these at some agreed upon point? This Society might request the aid of the Department of State in bringing about this coöperation. The task of collecting, reducing and publishing might be undertaken by the Society if it felt able, or otherwise be assigned to one of the governmental Bureaus, or to a joint Committee from the Coast Survey, Geological Survey and Weather Bureau. It is of interest to note that in the last appropriation bill for the last named Bureau Congress provided:

> "for necessary expenses in the City of Washington incident to collecting and disseminating meteorological, climatological and marine information; and for investigations in meteorology, climatology, *seismology,* evaporation and aerology, $110,000"; and in almost similar words for expenses outside of Washington, $1,201,150. (The total appropriation for this Bureau was $1,682,050.)

The work of publishing reports of local earthquakes has already begun with the issue for December, 1914, of the *Monthly Weather Review.* A suggestion from this Society might secure permission from Congress to extend the list and include world-wide reports. There should also be prepared reliable charts of seismic activity in detail for states and national domains; and in more general form for the world. There is probably ample material available now for this purpose.

Isolation of seismological observatories is not advisable. There should be close touch with some astronomical or meteorological institution. True this is an age of specialization, and life for all of us is so crowded that one may not deliberately step beyond the threshold of his chosen domicile; but experience teaches that in the application of knowledge the greatest results follow combined and synchronous work. Differentiation is good, but coordination and coöperation are needed now in seismology, and the geophysicist may pattern after the aerophysicist. Every seismographic observatory should be to some degree a pan-observatory, that is, an observatory where waves transmitted through earth, sea and air, and also through the ether, could be recorded and correlated. The Ebro Observatory at Tortosa, Spain, may be instanced as the prototype of the pan observatory, for here are combined solar physics, aerophysics and geophysics. Certainly no seismological observatory may dispense with open scale barographs. Compressional waves in the air must be recorded in connection with all volcanic outbursts. Accurate knowledge, too, of the general pressure distribution, the movements of individual "highs" and "lows," and the slow swinging or displacement of the axes of the more permanent areas, the sub-seasonal hyperbars and infrabars, formerly called "centers of action," is essential in seismology. Otherwise the minor markings, the tiltings and the microseisms are without explanation. In a certain sense, seismographs are microbarographs. It frequently happens that within a period of twelve or even less hours there will be an increase or a reduction in pressure equivalent to a loading and unloading of 1000 kilograms on each square meter of a block of the earth's surface 1000 by 500 kilometers. A rapid and convenient way of estimating the change in load, and indirectly a measure of the stress produced, is afforded by the new method of reading pressure in dynes or units of force rather than the old unit of linear height of a column of mercury. For example, in the storm of March 1, 1914, there occurred the lowest pressure known on the North Atlantic seaboard. In force units this was 941 kilobars or kilodynes (in the old style 28.47 inches). Taking a standard atmosphere as 1000 kilobars, it is at once evident that there was a decrease of 60 kilobars or 6%. But it is not so much the loading and unloading at the place of record as it is the loading at certain other points at the same time, which establishes the condition of strain and the resulting frequency and intensity of microseisms. It is what may be called the "seesawing" effect which is important. At present it is assumed that most microseisms are due to surf beating; and there appears to be a decrease with distance from the coast, and also a marked prevalence at certain sea-girt stations. But the pressure gradients must be carefully studied as productive of earth strain and sensitiveness to the propagation of vibratory movements due to differential loading.

Algué, Denison, Klotz, Hecker, Galitzin, Linke, Schneider and others have called attention to the significance of microseisms and storm movement and the use of the seismograph to record what has been somewhat poetically called "the tread of the hurricane." And there is some truth to the expression as well as poetry. Through the courtesy of Dr. Klotz there are shown (not reproduced) the Canad-

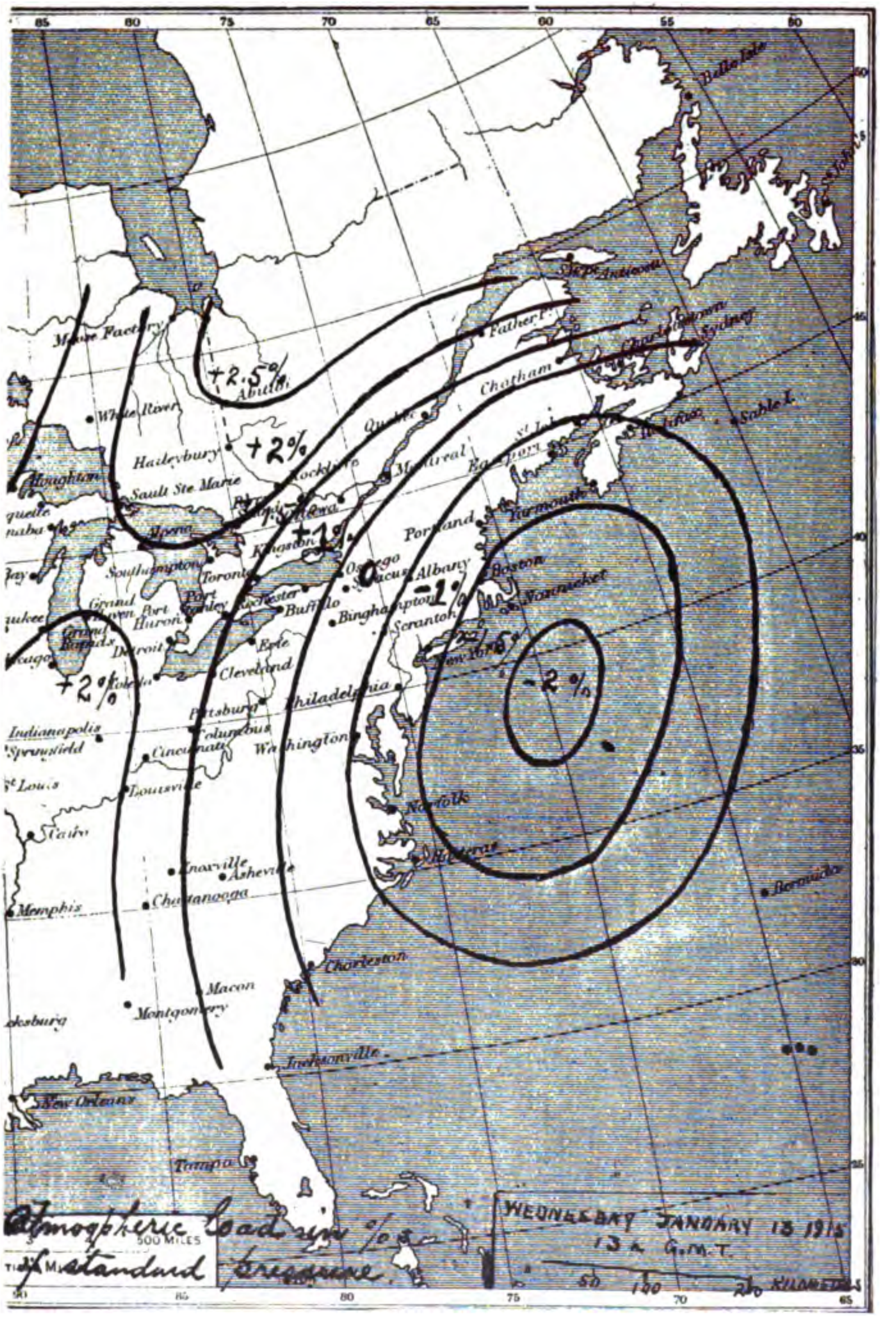


Fig. 1. Atmospheric load in percentages of standard pressure at times of microseisms, Ottawa-Cambridge. January 13, 1915.

ian weather map of January 13, 1915, and the microseisms recorded at Ottawa. Similar microseisms were recorded at Cambridge. In fact we anticipate and forecast microseisms when a "low" of a certain type is moving up the Atlantic coast. In Fig. 1 there is reproduced a rough diagram of the atmospheric load over the Atlantic seaboard, in percentages of a standard atmosphere.

It is also a matter of some consequence that seismological observatories should be equipped with pressure tube anemographs, Dines' for example, in order that there shall be available continuous records of the gustiness of the wind. The ordinary Robinson anemometer is not of much use in this connection.

Shall we urge the further establishment of seismological observatories in our country? Others may hold a different opinion, but to the speaker it would seem as if we had already a sufficient number. The response to the appeal made by this Society nine years ago was both prompt and widespread. And we must in this connection pay tribute to the Jesuit Colleges of our country for the readiness with which they established and maintain a chain of stations of high order. It is hard to select one where many deserve praise, but the Society would not be willing, I think, to have the effective work of Father Odenbach passed over without notice.

If there is to be further extension of university work, two purposes should be kept in view: first, the education of the public to a proper knowledge of earth movements and their significance; and second, the application of knowledge for the common good. I shall not dwell upon the engineering and economic aspects, for these will be amply discussed elsewhere. Rather would I lay stress upon the opportunity that now offers for investigation by individuals. The work heretofore attempted abroad must be taken up in earnest on this side of the Atlantic, and I might add, on this side of the Pacific, for we are not unmindful of what Japan has accomplished. Our Society is the result of what at the time appeared to be colossal misfortune; but in which some elements of good have since been recognized. May we dare to hope that some small measure of good may yet flow from the confusion and horror of the European situation?

In preparing this paper I came across the first call to consider the question of organizing. (Copy appended.) For several years the Society required much tender nursing, and there were many who questioned the need and the future. Not until March, 1911, did the first number of the Bulletin appear; and as our membership was small and our means limited, it required faith to venture thus far. But help came and through the generous and entirely unsolicited aid of Mr. Robert W. Sayles the stability of the BULLETIN is assured. Eighteen quarterly numbers have appeared, and we have no reason to be ashamed of the quality of the contributions to science published therein. The growth and usefulness of the Society is generally recognized; we have some reason to feel proud and would, were it not that our task has only begun. New occasions teach new duties, and the readjustments incident to the war impose new duties upon us. International comity must be restored, the friendships that have seemingly fallen apart must be re-established; and it devolves on us to hold aloft for awhile at least the torch dropt by runners in a war-torn land. Our Society can do no better work than try to re-establish the bond of union among seismologists of all nations.

Editor's note.—President McAdie desires to have suggestions and criticisms concerning the various points touched upon in his address. A symposium of these will be published in the December number of the BULLETIN, and all who read the article are invited to contribute.

THE EARTHQUAKE IN THE IMPERIAL VALLEY, CALIFORNIA, JUNE 22, 1915.

By Carl H. Beal.

Introduction

One of the severest earthquake shocks that has been felt in California since that of April 18, 1906, originated in the Imperial Valley in the extreme southeastern corner of the state on the evening of June 22, 1915, and was perceptible over an area of approximately 50,000 square miles.

The disturbance consisted of a fore-shock at about 7:40 p.m.; a heavy shock, which cracked and destroyed buildings and overturned chimneys at about 8:00 p.m., and another heavy shock nearly an hour later, which completed the destruction of the buildings already affected. These main shocks were followed by a long series of after-shocks which have continued up to the present time and varying in intensity from II to VI of the Rossi-Forel scale.

The intensity of the destructive shocks in the epicentral area was as high as IX, Rossi-Forel scale, and six people were killed in the border town of Mexicali by the falling brick and adobe walls. Many buildings were either totally destroyed or badly cracked, and rendered so unsafe that they had to be torn down. The total damage is estimated to be $900,000.

Method of Field Study

It was impossible to get trustworthy information in any way except by going into the district affected and gathering it directly from those who experienced the disturbance. The writer accordingly was commissioned by the Seismological Society of America to visit the area affected and to gather from the residents directly all the available information in regard to the shocks and, so far as necessary, to determine the geological structure in and about the Imperial Valley.

Starting at Los Angeles, a trip was made by automobile to El Centro by way of San Diego. Inquiries made along the road show that the intensity consistently increased toward the Imperial Valley.

From El Centro side trips were made north to the towns of Imperial, Brawley, Rockwood, and points in the Colorado Desert east and west of those places. The Superstition Mountains were also examined and the general geologic structure was determined. Inquiries were made of the people living east and west of El Centro as far as there were any settlements, and the towns of Heber, Calexico, and Mexicali were visited, in addition to numerous ranches on both sides of the international boundary.

A trip was also made to Volcano Lake and examinations were made of the hot springs near its margin, and of the extinct crater of Cerro Prieto, or Black Butte, from which a number of people claimed to have seen smoke and steam issuing prior to and during the earthquake. The long distance telephone was used extensively in obtaining information from distant points, and many letters of inquiry were sent to towns which it was not convenient to visit.

On the return trip to Los Angeles the Peninsula Mountains between the Imperial Valley and the coast were examined, and Descanso, Julian, Santa Ysabel, Warners Hot Springs and the Coahuilla Indian Reservation were visited and short side trips were made from those places to determine the location of some of the larger faults shown on Fig. 1. From the Coahuilla Valley the work was extended along the San Jacinto fault, which was traced southeast from Hog Lake nearly to the edge of the desert. The projection of this fault passes through the Imperial Valley.

The trip was again resumed to the northwest along the western base of the San Jacinto mountains as far as Riverside, where more information was obtained regarding the location of the San Jacinto fault.

In determining the epicenter of an earthquake by field study it is necessary to obtain from observers by judicious questioning the intensities at as many places as possible. The intensity at any locality is ordinarily inferred from the disturbances and sensations reported by observers and by the extent to which the buildings are damaged. The application of the Rossi-Forel scale of earthquake intensities is unusually difficult in the region under consideration on account of the peculiar construction of the buildings. Most of the buildings are low one-story structures made of rough, upright timbers about which screen wire is nailed, and there are no chimneys. It is, of course, impossible to determine the earthquake intensities by damage done to buildings of this kind.

Most of the area affected is but sparsely settled excepting approximately 250 square miles in the heart of the Imperial Valley. In the surrounding portions of the Colorado Desert and in the mountains on the west and southwest there are practically no settlers. Outside of the populated area the isoseismals are to be considered approximate only.

Location and Topography.

The Imperial Valley is in the Colorado Desert in the southeastern corner of California, with a small portion of it extending into the northern part of Lower California, Mexico. (Figs. 1 and 2.) It can be reached by a branch of the Southern Pacific Railroad, which leaves the main line at Niland on the northern margin of the desert and runs south through the irrigated district into Mexico, where it turns eastward and finally joins the main line again a few miles west of Yuma, Arizona.

From San Diego, 126 miles to the west, the valley may be reached

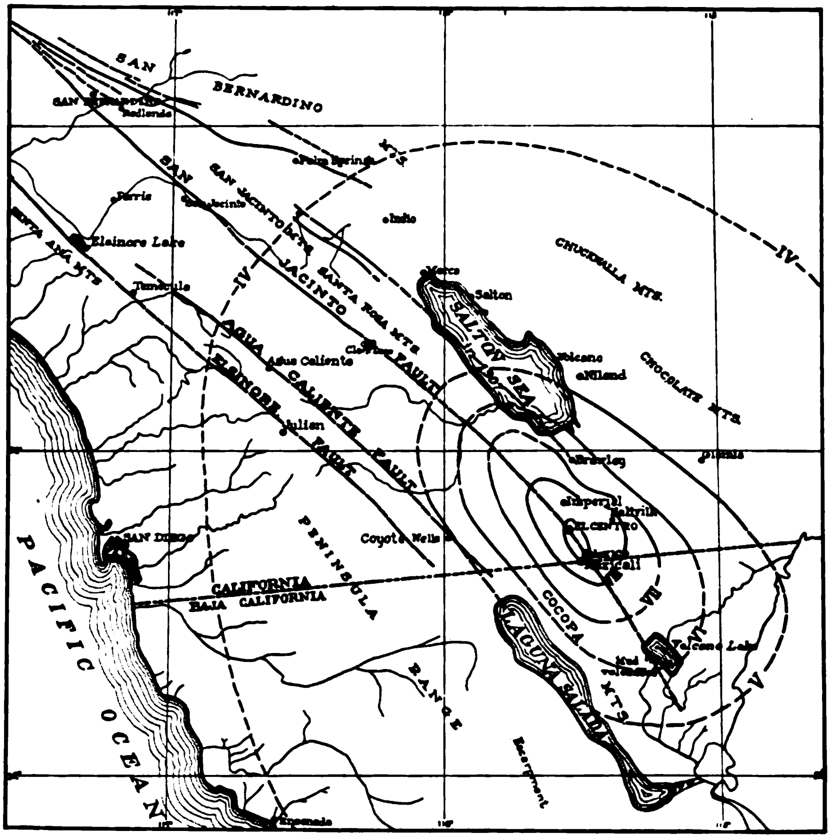


Fig. 1. Map of a portion of Southern and Lower California showing the distribution of the intensities of the Imperial Valley earthquake of June 22, 1915, and the location of some of the faults. Solid lines indicate a proved fault or fault zone and broken lines indicate a probable fault or fault zone. Scale: One inch equals approximately 40 miles.

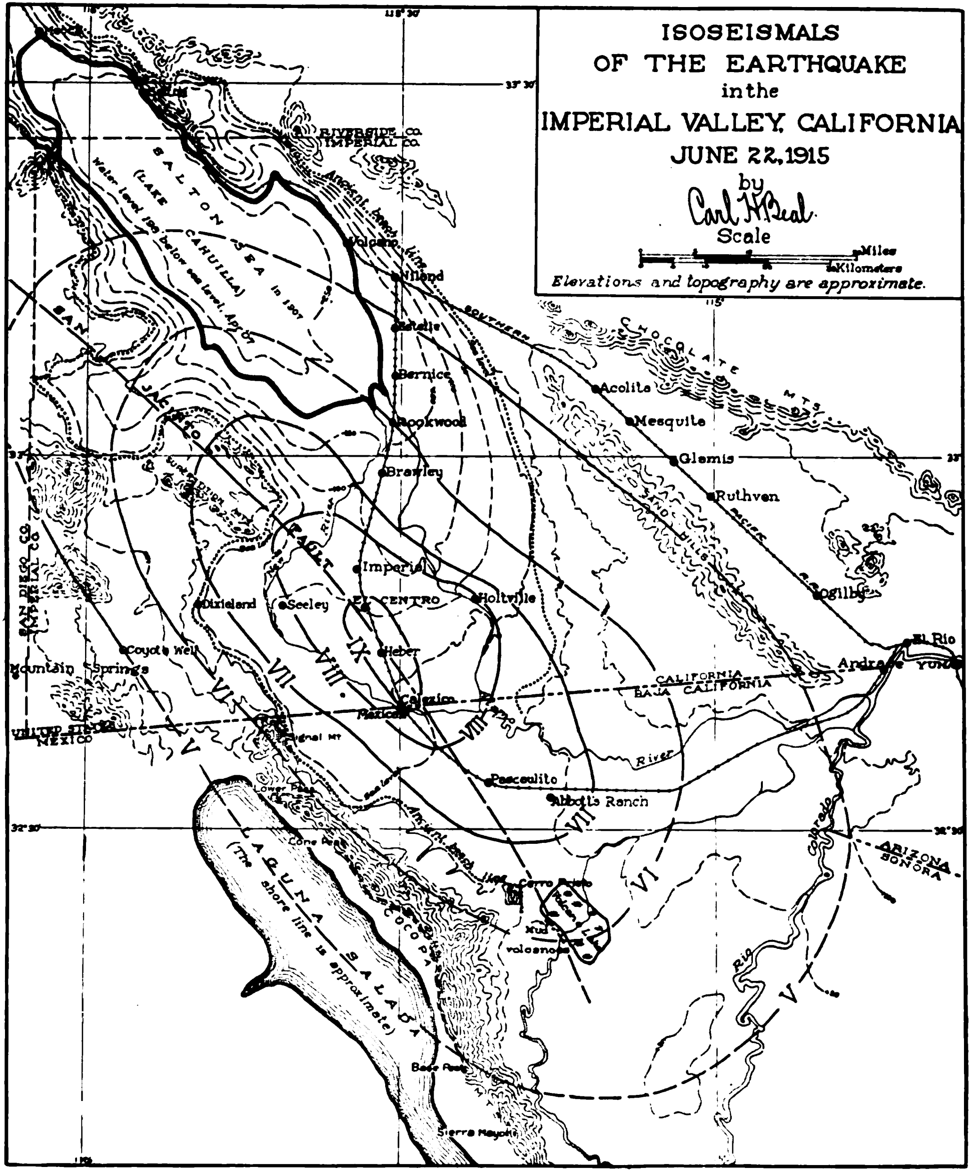

ISOSEISMALS
OF THE EARTHQUAKE
in the
IMPERIAL VALLEY, CALIFORNIA
JUNE 22, 1915
by
Carl H. Beal
Scale
Miles
Kilometers
Elevations and topography are approximate.
116°
115° 30'
115°
33° 30'
33°
32° 30'
RIVERSIDE CO.
IMPERIAL CO.
SALTON SEA in 1907
(LAKE CAHUILLA)
Water level 1905 below sea level, Apr. 07
Ancient beach line
Volcano
Niland
Estelle
Bernice
Brookwood
Brawley
Imperial
EL CENTRO
Holtville
Heber
Calexico
Mexicali
Seeley
Dixieland
Coyote Well
Mountain Springs
SAN DIEGO CO.
IMPERIAL CO.
UNITED STATES
MEXICO
SAN JACINTO
FAULT
New River
Signal Mt
SOUTHERN PACIFIC R.R.
CHOCOLATE MTS
Acolita
Mesquite
Glamis
Ruthven
SAND HILLS
Ogilby
El Rio
Andrade
YUMA
CALIFORNIA
BAJA CALIFORNIA
ARIZONA
SONORA
Colorado
Rio
River
Pascualito
Abbott's Ranch
Cerro Prieto
Mud volcanoes
Lower Pass
Cone Peak
COCOPA
LAGUNA SALADA
(The shore line is approximate)
Base Peak
Sierra Mayor
IX
VIII
VII
VI
V

Fig. 2.

over the Peninsula Mountains by a good automobile road, and from Los Angeles by a road through Redlands, San Gorgonio Pass and Mecca.

On the east of the Colorado Desert lie the Chocolate Mountains and on the north the Chuckwalla Mountains. These are typical, barren, desert ranges, poorly watered and almost devoid of vegetation. The western wall of the desert consists of the San Jacinto and Santa Rosa mountains. The mountains rise to an elevation of 10,000 feet, the eastern face resembling the barren ranges on the opposite side of the desert. South and west of the Santa Rosa mountains lies the Peninsula Range, which trends southward into Lower California.

Southwest of the Imperial Valley the flat desert floor changes abruptly to the steep eastern face of the Cocopa Mountains, a high, barren, forbidding range, poorly watered and entirely uninhabited.

Between the Cocopa Range and the Peninsula Range west of it, in a depression below sea level, is a fluctuating body of bitter, brackish water called Laguna Salada. This lake owes its origin, not so much to the slight rainfall of that arid region as to its connection with the lower reaches of the Colorado River, near the Gulf of California. During the high water stages of the river or during some of the frequent high tides on the gulf, this depression is partly filled with either fresh or salt water, which evaporates during the succeeding dry months. The surface of the water in the lake is said to stand at present at about twelve feet above sea level.

The Imperial Valley, lying in the Colorado Desert on the delta of the Colorado River, is almost entirely below sea level in a depression which has been filled in recent geological time by a body of water. This lake was at one time an arm of the Gulf of California, but was cut off by the building up and extension of the delta of the Colorado River into and across the gulf. In 1853, W. P. Blake, geologist for the Pacific Railroad Survey, recognized the relation of the lake to the Colorado River, and later named it for the Cahuilla Indians, who inhabited the margins of the lake. Mute evidence of the former existence of the lake is found in the beautifully preserved strand line, the average elevation of which is 42 feet above sea level (Fig. 2). The ancient beach line is plainly visible nearly everywhere about the ancient shores except on the Colorado River delta itself.

Geologic Structure of the Imperial Valley.

One fault, and perhaps two or three, are thought to pass through the Imperial Valley, but as very little geologic evidence is available, most of the conclusions regarding the existence of these faults are based upon the existence of hot and mud springs on the valley floor and on the character of the topography in the foothills and through the mountains along the west side of the desert.

The accompanying map (Fig. 1) of Southern California shows the general location of the more important faults which are shown by field study, or are believed on account of other evidence to exist. It is realized that the data are incomplete, and the evidence supporting the existence of the faults in Lower California is scanty, but it is thought advisable to publish on one map all the information obtained regarding this subject.

The rocks of most of the territory covered are chiefly crystalline schists, gneisses and granites, in which it is often difficult to obtain trustworthy geologic evidence of faults. In the mountains between the Colorado Desert and the Pacific Ocean there are at least three parallel major faults, probably running southeast into Lower California, which have been named as follows: the Elsinore fault, the Agua Caliente fault and the San Jacinto fault.

These faults, or zones of weakness, are thought to have been made during the elevation of the various mountain ranges in Southern California, and in the writer's opinion should very seldom be mapped as a single line, for it is believed that the faulting occurs in zones. Take, for example, the San Andreas rift. This is usually spoken of and mapped as a single line of displacement which extends from Cape Mendocino southeast to the Colorado Desert; but as a matter of fact, it is usually a narrow zone of discontinuous parallel faults, and for this reason should not be called the San Andreas rift throughout its entire length. This sort of faulting was observed at various localities on the San Jacinto fault, the zone being made up of a number of parallel faults. In some places the total displacement was apparently on one fault, which a little farther on would die out and another parallel fault a short distance to the right or left would begin.

Beginning at the eastern escarpment of the Santa Ana Mountains (Fig. 1), the Elsinore fault runs southeast through Temescal, Elsinore Lake, Murrieta and Temecula. It follows Carrizo Creek and the head waters of Santa Ysabel Creek a few miles east of Santa Ysabel. From here it probably continues on its nearly straight course down Banner canyon, but it was not proved farther southeast. It very likely goes through Mountain Springs, however, and strikes the international boundary near 116° west longitude. From here, if curved slightly south, it would pass on the west side of Laguna Salada, and probably coincide with the same great north-south fault described by Lindgren[1] along the eastern escarpment of the Peninsula Range about fifty miles south of the international boundary. If this is true the fault finally turns nearly south at about 32° north latitude and pursues its course along the western coast of the Gulf of California. The existence of this or another fault in the northern part of Lower California is further indicated by many hot springs along the eastern base of the Peninsula Range.

The Agua Caliente fault was named from Agua Caliente, or Warners Hot Springs, through which it passes. Beginning at latitude 33° 30′ north and longitude 117° west the fault trends about S. 55° E. along Temecula and Aguanga creeks, through Agua Caliente, probably through Carrizo Station and Coyote Wells, crossing the border line about ten miles east of the 116th meridian. From this point the fault probably passes through the mud volcanoes in Laguna Salada, and trends along the western base of the Cocopa Mountains. The country between Warners Hot Springs and Coyote Wells was not visited during the recent trip and no evidence of the existence of a fault was obtained. Near the Mexican boundary, however, there is evidence that a fault passes through Coyote Wells, but whether or not this is the Agua Caliente fault could not be definitely ascertained.

The fault which chiefly concerns us at present is the San Jacinto fault. It apparently branches from the so-called San Andreas rift northwest of Riverside and crosses the San Bernardino Valley, where its presence is suggested by hot springs and a scarp in the valley floor about two miles northeast of Colton. This scarp is a few feet high and can be followed about two miles. In the hills east of Riverside and along the western base of the San Jacinto Mountains the fault is shown by both geologic and topographic evidence. It is further proved to extend southeast of Thomas Mountain through the northeast side of the Terwilliger Valley (Plate 12, Fig. 3) and down Horse Canyon to a point about four miles above where it joins Coyote Canyon. Here the fault passes through the high mountain on the northeast side of Horse Canyon (Plate 12, Fig. 4) and across a spur of the Santa Rosa Mountains. Indications of the fault are visible farther southeast in Alder Creek as far as Clark Well. Between here and the Superstition Mountains, however, is a stretch of desert which was inaccessible in the season when our field work was done, and no evidence supporting the existence of the fault could be obtained.

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[1] Lindgren, W.: Geology of Baja California. *Proc. Cal. Acad. Sci.*, second series, 1, part 2, 173. San Francisco, 1889.

The Superstition Mountains lie in the line of the San Jacinto fault and were hurriedly examined on the recent trip. Although but little geologic evidence was available on account of the covering of dune sand, the topography suggests a fault between the main mountain mass and the low outlying range of knolls to the northeast.

The rocks of the southeastern portion of the Superstition Mountains, as far as they were examined, consist of Tertiary (?) sandstones which have been thrown into undulatory folds and are occasionally faulted, the determined structural lines striking approximately east and west. The fact that the topography indicates a fault and that the fault lies in the path of the San Jacinto fault strengthens the belief that the main zone of weakness continues from the San Gabriel Mountains northwest of Riverside to at least this point.

From the Superstition Mountains the southward projection of the San Jacinto fault lies entirely in the Imperial Valley and on the delta of the Colorado River. The only evidence found that supports its actual existence, however, is the fact that the fault if projected passes almost directly through El Centro, very close to Heber and Calexico, and if curved slightly to the south passes through the hot springs and mud volcanoes on the west side of Volcano Lake (Frontispiece). The additional fact may be cited that the isoseismal curves are elongated into concentric ellipses, with their major axes lying in the same direction as that of the prolonged fault. This point will be referred to later.

Two faults on the northeast slope of the Santa Rosa Mountains and nearly parallel to those discussed above are shown in Fig. 1, but they were not named for lack of sufficient proof of their extension into the Imperial Valley. If projected southeast and curved slightly to the south, they would pass through the many springs which emerge at the eastern base of the Santa Rosa Mountains, and farther southeast would extend along the Alamo River. The fact that artesian water is found in the vicinity of Holtville, east of the Alamo River, but nowhere west of the river, is an indicaton that a fault may lie somewhere between the two places.

Other faults are suspected to exist on the northeastern side of the Salton Sea and along the eastern side of the Imperial Valley; but as no geologic work was done there, and as no definite evidence of their location is available, lines representing the faults were not drawn on the accompanying map (Fig. 1). One of the most significant facts that points to faulting in this part of the Colorado Desert is the existence of active solfataras, or mud volcanoes, located about six miles south of the station of Volcano on the Southern Pacific

Railroad. These solfataras were submerged by the Salton Sea in 1907.

HISTORICAL

The Colorado Desert and the adjoining regions have been visited by earthquake shocks since the period of the earliest records. The Indians, who have lived for generations in the San Jacinto Mountains, tell of great earthquakes and hold certain places in fear on account of the frequency of the earthquakes which visit them. There are records of serious earthquakes occurring along the San Jacinto fault, and its probable extension through the Imperial Valley. An account of the earliest and most severe shock since 1850 was given by W. P. Blake in volume V, page 115, of the Pacific Railroad Reports, as follows:

"Fort Yuma and its vicinity appears to have been particularly liable to . . . earthquakes, for many have been experienced since the establishment of the military post. On the 9th of November, 1852, the camp was violently shaken by an earthquake, and the shocks continued almost daily for several months later, and were so frequent and expected as not to excite remark . . . The first shock threw down a portion of Chimney Peak and opened fissures and cracks in the clay strata of the desert bordering the Colorado. At the same time Major Heintzleman, the commanding officer of the post, observed a column of steam rising from the desert in a southwesterly direction at a distance of about forty miles. Several weeks afterward he visited and examined the locality and found a small mud volcano in an active state."

The earthquake referred to probably originated on the San Jacinto fault to the west, and the mud volcanoes mentioned are undoubtedly the same as those on the west side of Volcano Lake. During the following decades, while Fort Yuma was an important military post and the westernmost camp before crossing the Colorado Desert, several earthquakes were recorded.

At Carrizo Station, one of the stations on the old transcontinental stage line, a serious earthquake occurred in February, 1892, which destroyed all the adobe buildings at that place.[2] That shock probably originated on the Agua Caliente fault.

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[2] Mendenhall, W. C.: Some Desert Watering Places in Southeastern California and Southwestern Nevada. Water Supply Paper, U. S. G. S., No. 224, p. 89. Washington, 1909.

CAUSE OF THE EARTHQUAKES OF JUNE 22, 1915

The Superstition Mountains are said to have been so named on account of the fact that long ago the Indians visited them for some ceremony, and while there they were shaken from their feet by a violent earthquake. From that time they have held this low range of hills in awe, and the legend has had its influence on the white people, for many of them claim that daily rumblings can be heard from the direction of those moutains, and that the shock of June 22, 1915, certainly came from there.

The mud volcanoes and Cerro Prieto near Volcano Lake are supposed by many to have caused the shock, but although the mud volcanoes showed greater activty after the earthquake, upon examination the extinct volcano, Cerro Prieto, showed no signs of having erupted recently.

The San Francisco earthquake of April 18, 1906, furnished tangible evidence that it was caused by the slipping of the rocks on each other, and the break in the surface could be traced from the Mendocino County coast southeastward to near San Juan in Monterey County. Although the recent Imperial Valley earthquake was by no means so widespread, it was certainly a disturbance of equal violence, and it seems reasonable to suppose that the shock originated by a dislocation on a neighboring fault. The area affected, however, was relatively small, and the Imperial Valley lies in a basin-like depression which is deeply filled with hundreds of feet of an unconsolidated alluvial deposit. In this case, even if the displacement on the underlying bedrock had been several feet, the dislocation of the bedrock would probably have been masked by the alluvium covering, and would not have been visible at the surface as a dislocation.

The San Jacinto fault has been traced from the San Gabriel Mountains to the northwest toward El Centro and nearly to the edge of the desert; it has been shown that it very likely exists in the Superstition Mountains about fifteen miles northwest of El Centro; and it probably passes through the mud volcanoes on the west side of Volcano Lake. With these facts before us it seems very likely that the disturbance of June 22d originated on the San Jacinto fault, which is believed to be prolonged in the bedrock underneath the Imperial Valley.

Location of the Epicenter

It was by mere chance that the epicentral area of the earthquake included the most thickly populated part of the Imperial Valley. Had the epicenter been twenty-five miles to the east or to the west it would have been difficult or impossible to locate it with any degree of certainty. The shocks of June 22d, however, were certainly heaviest in the district extending from El Centro to Calexico, and the epicenter must have been at some point or on some plane within the IX isoseismal shown on Fig. 2. It is impossible to assign a more definite location to the epicenter, for the surface of the ground was nowhere broken or dislocated.

Careful inquiry was made of nearly every one consulted in regard to the relative intensity of the two strong earthquakes, and sufficient information was obtained to prove that both of them must have originated from very nearly the same focus. This is an interesting point in connection with the fact that the intensities of the two shocks were practically the same.

Distribution of Intensities

The earthquake shocks of June 22d were felt by very few people in Los Angeles, where the intensity was between II and III, and by no one in Palmdale in the Antelope Valley, or as far north as Barstow in the Mohave Desert. A number of people in the San Bernardino Valley felt them, but very few observed them at Needles, where the intensity was III. The intensity was III at San Diego; between III and IV at Ensenada, Lower California; IV at Tecate on the international boundary; IV at Warners Hot Springs; IV at Indio; between III and IV at Parker, Arizona; and two Indian hunters report that they did not feel it at San Felipe, a water-hole on the west coast of the Gulf of California, about 125 miles south of El Centro.

The isoseismals shown in Figs. 1 and 2 represent the intensities of both shocks, as the two were apparently from the same focus, and, as already noted, of about the same severity. The lines representing the highest intensities are close together, and are confined to a small area within the Colorado Desert. The IV and V curves, however, are farther apart and enclose a much greater area. The III isoseismal is not shown on the map, but the distance between it and the IV curve is still greater than that between the IV and the V. The distribution of the isoseismals themselves suggests, if it does not prove, that the shock originated under the valley, which is deeply filled with soft, unconsolidated material. Through such material earthquake shocks are transmitted more slowly but with greater amplitude, and consequently do more damage than in the more solid rocks of the mountains, where they are transmitted more promptly but with smaller amplitude and consequently do less damage. The elliptical shapes of the inner isoseismals suggest that the disturbance probably originated along a plane rather than at a point.

Although the nearly circular III isoseismal could not be shown in Fig. 1, it serves as an approximate boundary to the area over which the shocks were strong enough to be perceptible to persons at rest. It bounds an area of approximately 50,000 square miles.

The accompanying map (Fig. 2) shows the IX isoseismal as an elongated ellipse, the major axis of which lies in the projection of the San Jacinto fault. This elliptical isoseismal incloses the towns of El Centro, Heber, Calexico, and Mexicali. The buildings of all of those towns are constructed alike and of the same kinds of material, so that one can readily compare the relative intensities. The intensity as judged by the damage to buildings seems to have been practically the same in the four towns, with that at El Centro a trifle more severe. Evidence collected from observers living on all sides of these towns shows clearly the location of the isoseismal; the two shocks did much damage to practically every brick and adobe building within the ellipse.

No difficulty was experienced in locating the VIII isoseismal, which, although somewhat generalized in places to take into account the character of the structures, etc., that control the location of the isoseismals, represents the intensity fairly well.

This line curves eastward in the direction of Holtville, a fact that could not at first be reconciled with other data; but it was found that artesian water occurs on the east side of the Alamo River in the vicinity of Holtville. The saturation of the soil by water is thought to account for the high intensity in that locality, and for the resulting irregularity in the curve.

The northeast and southwest sides of the VII isoseismal were readily located, for they fall within the settled district. The ends of the ellipse, however, could not be so accurately determined, on account of the sparsely settled character of the Superstition Mountains and of the Volcano Lake region.

The isoseismals of lower intensities are determined with less precision as the intensities which they represent decrease in severity.

It was possible to locate accurately a few points on each low intensity curve, but the lack of any settlers in some of the country affected and the indifference of some of the observers to earthquakes of an intensity below V made the collection of more complete information impossible.

DAMAGE

The most serious damage caused by the recent earthquake was confined to a narrow north-south zone including El Centro, Heber, Calexico, and Mexicali. The total damage is thought not to exceed $900,000, and a large percentage of this was due to the poor construction of the buildings throughout the district affected, as very few of the more recently constructed buildings suffered more than the loss of fire-walls and cracks in the concrete or brick walls. The older brick buildings were erected during a period of rapid growth, and are usually not more than two stories in height, with walls about eighteen inches in thickness. Approximately one hundred of these buildings in the Imperial Valley were damaged to such an extent that they had to be rebuilt.

The greatest destruction was in El Centro, the largest city in the valley, where the damage is reported at about $600,000. A few of the buildings were completely demolished, but in every case the more carefully constructed buildings withstood the shock fairly well. More of the east and west walls apparently fell than the north and south walls, and in many instances all the plastering was completely stripped from them, while that on the north and south walls was only slightly cracked. The character of the damage done to some of the buildings in the different towns is shown in Plates 13, 14, 15, 16 and 17.

Besides the walls falling from many of the office buildings, the Masonic Temple was wrecked, the Imperial Valley Bakery and the Broadway Garage were practically demolished, and the walls of the new Barbara Worth Hotel and those of the El Centro High School were badly cracked. Practically all the brick chimneys in town fell or were so badly shattered that they had to be rebuilt. Most of the chimneys were low and solidly built. Many dishes were thrown from the shelves and broken, and a number of window panes were shattered by the twisting of the buildings. The earthquake shocks and a resulting fire completely demolished the building occupied by the Delta Mercantile Company. A view of the ruins is shown on Plate 13, Fig. 5. In Calexico two frame houses were completely destroyed by fire caused by the earthquake. Much damage by fire was averted, however, by the electricity being immediately switched off at the power station as soon as the shock was felt.

No one was killed in El Centro, although many suffered minor injuries by the falling bricks, glass, plaster, and bric-a-brac. That so few people were hurt or killed was due to the fact that all the destruction was caused by two separate shocks, which were separated by about an hour, the first occurring at about 8 p.m. This first vibration overthrew very few walls, but cracked and weakened them so that the next heavy shock at about 9 p.m. did much damage. The people, however, were so generally frightened by the first heavy shock and its succeeding series of after-shocks that none ventured to return to the buildings, and as a result practically the whole population was standing in the middle of the streets when the wrecking of the buildings was completed by the arrival of the second heavy shock at nine o'clock. This was true in all the damaged towns excepting the small border town of Mexicali, just south of the international boundary. At this last-named place the gambling and dance halls were running full blast when the first shock occurred. A general uproar and exodus from the buildings followed, but loath to abandon the merrymaking for even a few minutes, many persons ventured to return to the unsafe buildings. When the second shock arrived the weakened buildings collapsed, pinning many underneath, killing six, and injuring a large number.

The towns of Calexico and Heber were about as badly damaged as El Centro, but not being so large the rebuilding cost is less. Holtville and Imperial lay outside the area of greatest intensity and suffered no great damage, although most of the chimneys fell and a few fire-walls collapsed. Inside the VIII isoseismal there was much damage done, such as throwing of dishes and bric-a-brac from the shelves, the overthrow of chimneys, and the disturbance of all sorts of movable objects. Fortunately, none of the ditches or intakes of the extensive irrigation system was broken, although a few cracks were formed parallel to the levees, due to the lurching of the soil.

In such a district as this, which may be visited by severe seismic disturbances in the future, earthquake-proof buildings should be constructed. Reinforced concrete costs but little more and has been found to withstand a shock of almost every intensity up to a point where the ground actually opens. Hence for a small extra outlay of expense in building, many lives and the cost of reconstruction may be saved in the future.

EFFECTS

During the incursion of the Colorado River a few years ago the beds of New and Alamo rivers were deeply cut through the soft fine soil. Many of these steep bluff-like banks were thrown into the bed of the river by the heave of the ground during the earthquake shocks, and the marshy bed of New River northwest of El Centro was cracked in many places. Large areas of this kind of ground sank from a few inches to a foot or more, and water flowed from the cracks for some time. A mule driven along within a few yards of one of these places at the time of the first shock was suddenly thrown from his feet; and about an hour later, as he was being driven back by the same spot, he was again thrown by the second heavy shock. There is little wonder that the driver thought the locality bewitched.

Another person was motoring east toward El Centro when the first heavy shock occurred. The machine suddenly slackened its speed, but responded with a jerk after two or three seconds. In another case a man was driving south toward El Centro and the reverse was experienced, the machine suddenly lurching ahead at a high rate of speed and slowing down to its original rate after two or three seconds.

On the west side of Volcano Lake are a number of hot and cold solfataras, locally known as "mud volcanoes." As no one lives near them it was impossible to determine the exact effect on the solfataras by the recent earthquake shocks. People living about fifteen miles north of these craters, however, report that columns of steam were seen rising from the vents for a number of days following the earthquakes, and occasional explosions were heard from that direction. These reports were verified by inquiry of other observers; and although many exaggerated statements were made, an increase in activity seems to be a natural result of the movement along the San Jacinto fault, which is thought to pass through them. This same phenomenon was noticed and investigated by Major Heintzleman, the commanding officer of Fort Yuma, after a severe earthquake in 1852.[3]

Many of the people consulted who live on irrigated farms claim that after the earthquakes one-third more water was required to properly irrigate a tract of land, and many holes in the fields were found which had not previously been known to exist.

The effect on animals caused by the strong shocks and by the

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[3] Blake, W. P., in Pacific Railroad Reports 5, 115. New York, 1858.

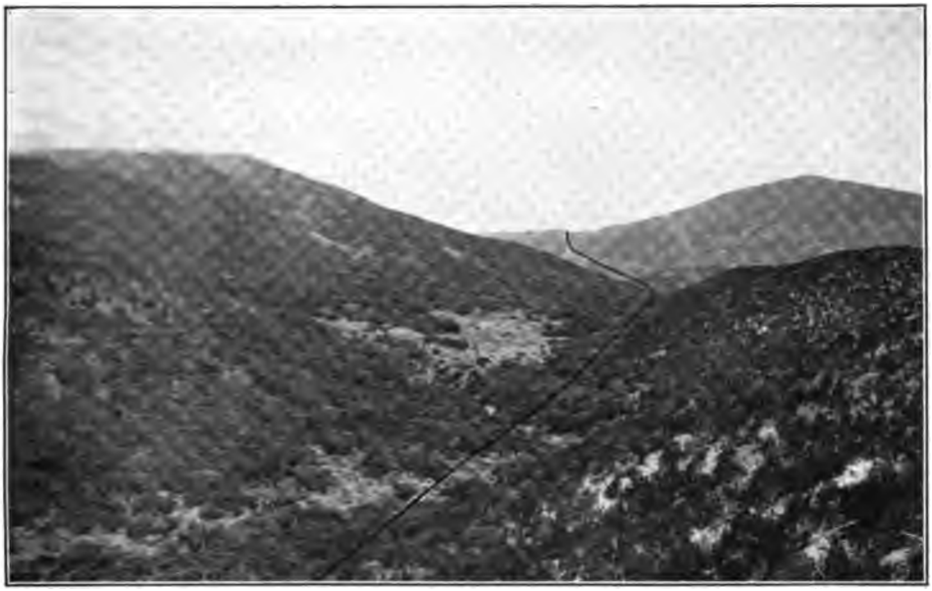

Fig. 3. The San Jacinto Fault on northeast side of the Terwilliger Valley looking northwest. The Fault crosses a spur of Thomas Mountain in the distance.

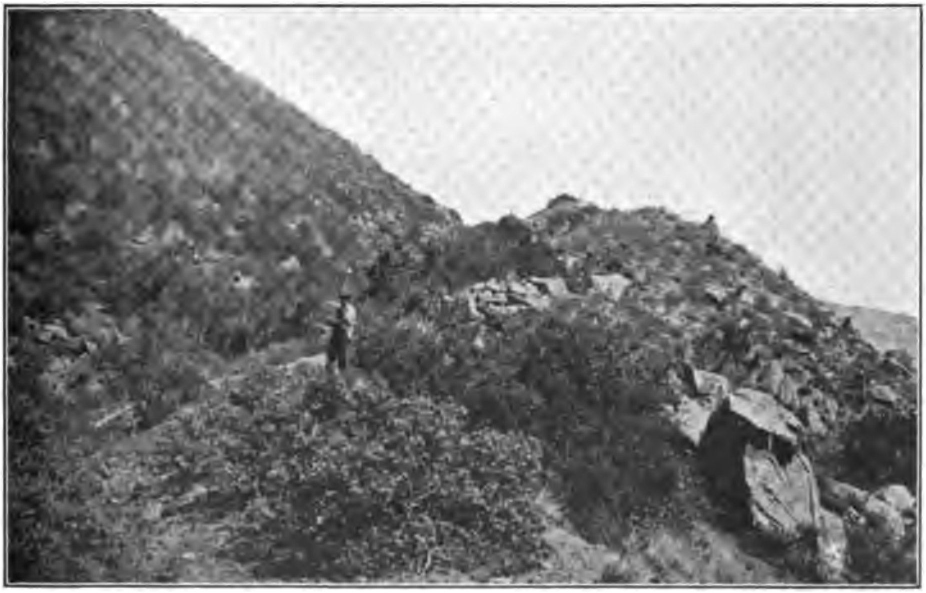

Fig. 4. At this locality the San Jacinto Fault passes through the steep slope on the northwest side of Horse Canyon. The trough shown in the illustration ascends from the level of the canyon diagonally up the mountain side.

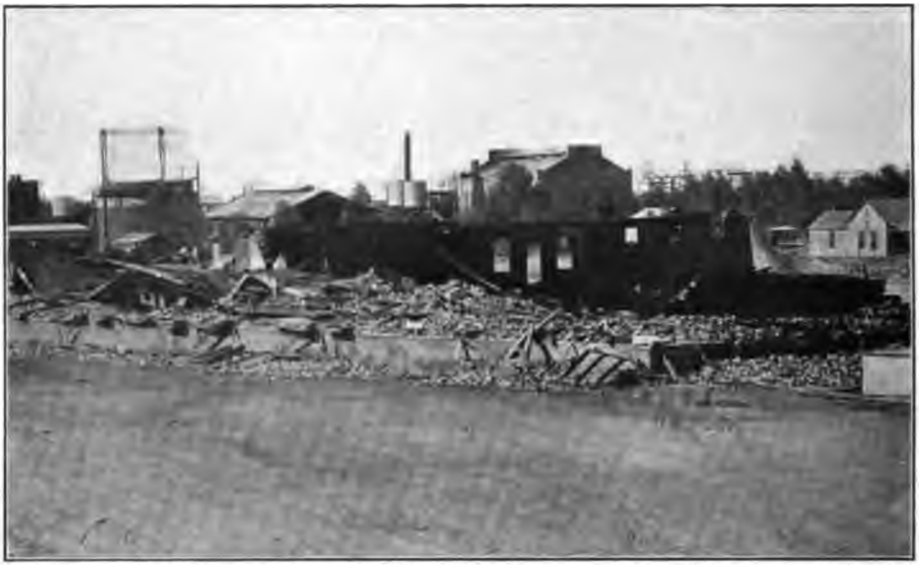

Fig. 5. The remains of the building cf the Delta Mercantile Company, El Centro, California, showing the results of earthquake and fire.

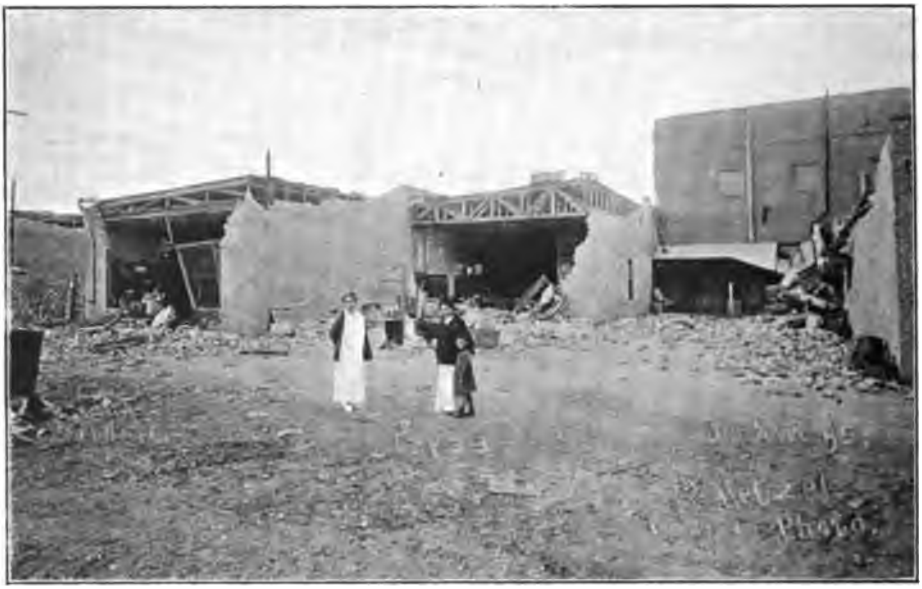

Fig. 6. Typical view of the earthquake damage in El Centro, California. Pool hall on the left, the office of the Imperial Valley Press in the center, and Dunaway's on the right.

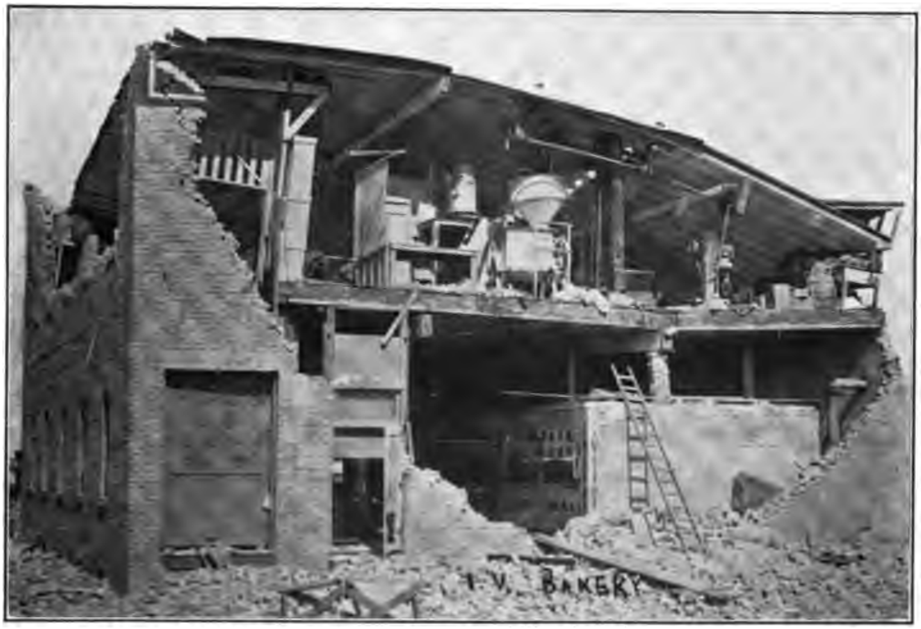

Fig. 7. The Imperial Valley Bakery, El Centro, California, after the earthquake of June 22, 1915.

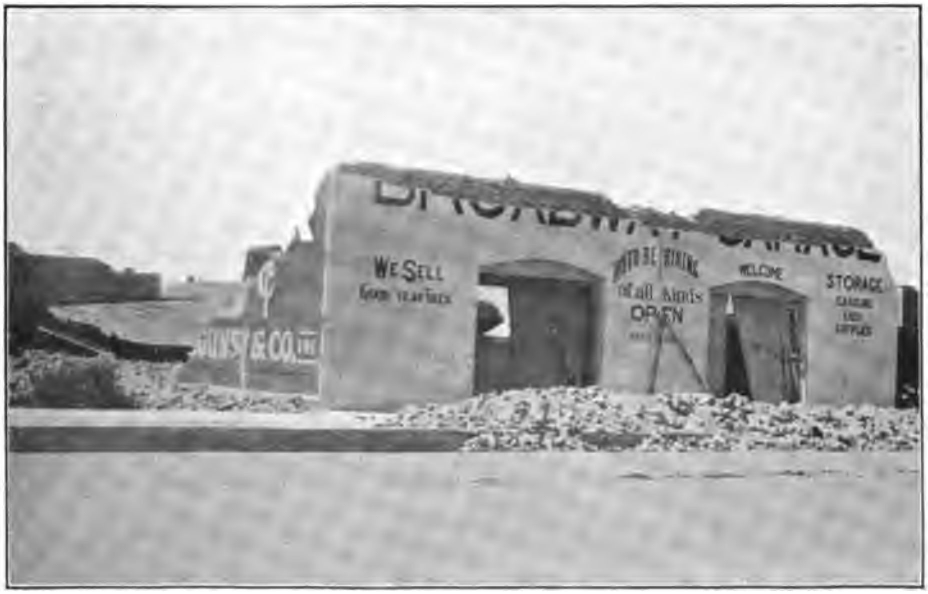

Fig. 8. The Broadway Garage, El Centro, California, after the earthquake of June 22, 1915. This building is said to have been very poorly constructed.

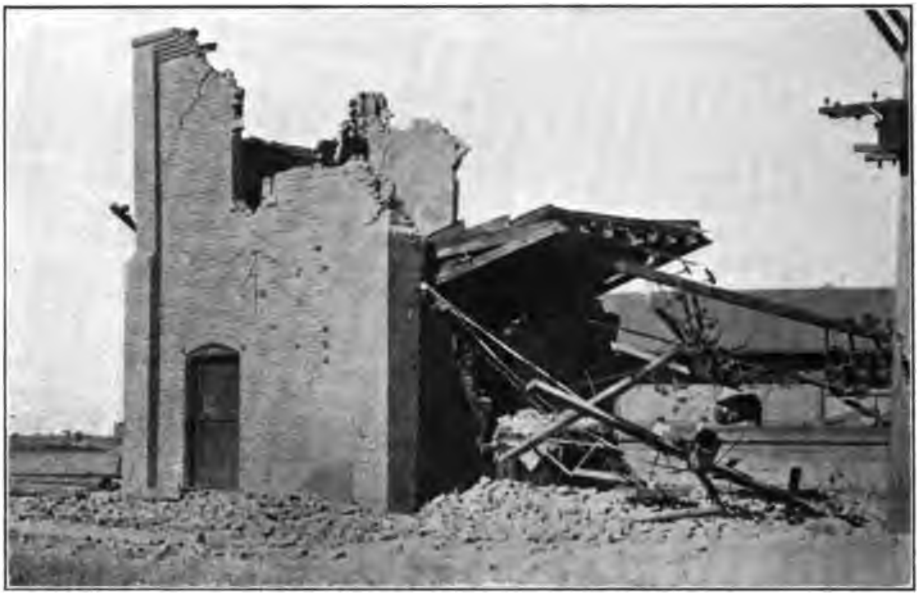

Fig. 9. Results of the earthquake at Calexico, California. Transforming station of the Holton Power Company.

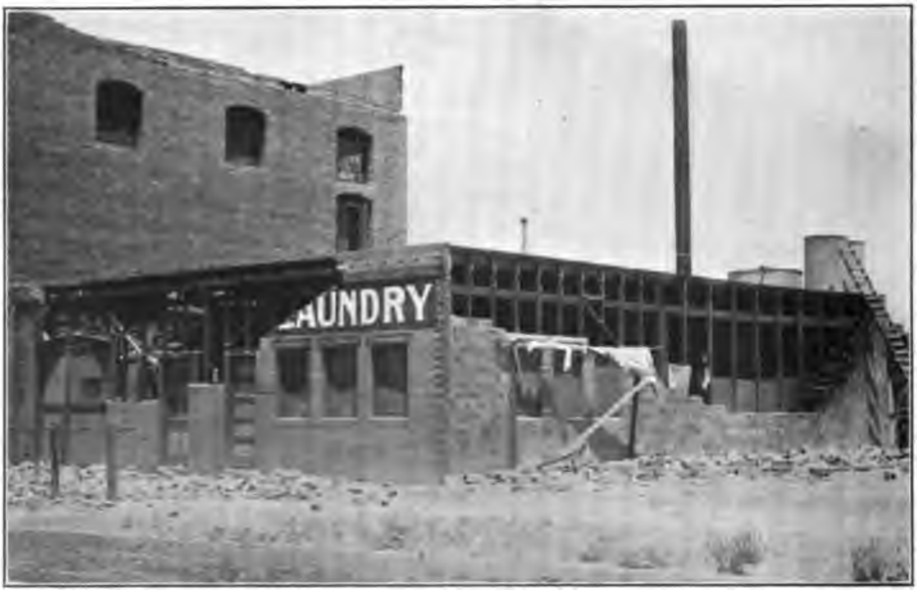

Fig. 10. Typical view of the damage done in Calexico. The building shown is the Calexico Laundry and was constructed of tile.

more serious after-shocks is noteworthy. The horses standing in the corrals exhibited great nervousness before some of the earthquakes, and during the shock became much frightened and snorted and galloped madly around the enclosures. Many observers claimed that the horses became nervous as much as an hour before the shock, but as a rule the noticeable difference in their actions preceded the shock by only a few minutes. It was noticed in many places that just before the shock horses harnessed to wagons stopped and braced themselves as if to prepare themselves for the shock.

Most of the dogs showed fear and howled before the earthquakes, and during the shock bristled up as if preparing for some antagonist. Chickens and cats showed alarm only during the shocks; but the cattle in the fields acted much like the horses.

TIME

It was difficult to obtain any accurate information in regard to the time of the shocks at the epicenter. Most of the clocks were stopped by the first shock, and as they were not started again in time to record the second one, only approximate times could be obtained. Very few of the clocks in the valley were in accord, and some of the clocks which were supposed to be trustworthy did not agree with others of supposed accuracy. The results of the inquiries on this point are given, however, in order that the reader may get an idea of the approximate time of the shocks.

The Western Union clock in El Centro is reported to have been stopped by the first earthquake between 8:02 and 8:03 p.m.; but this does not agree with other records obtained which appear to be just as trustworthy. The railroad agent at Calexico timed the arrival of both shocks and reported that the first arrived at exactly 7:55 p.m. and the second at 8:55 p.m. The clock in the Calexico Hotel was stopped by the second shock at 8:55 p.m. A jeweler states that the first shock stopped a well regulated clock in his store between 7:59:40 and 7:59:50 p.m. and that the second shock occurred about 8:57 p.m. One clock in Holtville was stopped at 8 p.m., while the railroad clock was not stopped by the first shock, but it was stopped by the second one at 8:50 p.m. A clock in a barber-shop in Holtville was apparently stopped by the first shock and started again by the second, as it was about an hour late when observed the next morning.

At Brawley the Western Union clock was stopped at 8;55 p.m. and the railroad clock at 8:59 p.m. At Heber the railroad clock stopped at 8:57 p.m. Mr. D. Witter, of the U. S. Weather Bureau at Brawley, timed the first shock at 7:59 and the second at 8:59 p.m. At San Diego the records given out by the Weather Bureau are respectively 8:02 and 8:58 p.m.

Mr. Albert J. Newlin, of the University of Santa Clara, reports that the preliminary wave of the first earthquake was registered at Santa Clara on the east-west component of the seismograph at 8:00:23 p.m., the long waves arriving at 8:02:19, while the corresponding waves of the second heavy shock were registered at 8:57:37 and 8:59:22 p.m., respectively (Pacific Standard time).

The writer is indebted to Mr. F. P. Ulrich, Observer at the Tucson Magnetic Observatory, for the records of the earthquakes at Tucson. The first preliminary tremors of the first shock were registered on the east-west component of the seismograph at 7:59:46 and the long waves began at 7:00:57 p.m. The corresponding waves of the second severe shock were registered on the same component of the instrument at 8:56:31 and 8:57:28 respectively (Pacific Standard time).

DURATION

Had either shock been of much longer duration there would have been much more damage. The first earthquake was carefully timed by a trustworthy observer, who found that it lasted eleven seconds. The duration was therefore so short that the buildings had scarcely begun to vibrate when the shock ceased. The second shock was usually reported to have been a trifle shorter than the first, but a harder one and accompanied by a twisting jerk. Its duration was probably between five and ten seconds. Many observers who had experienced the San Francisco earthquake of April 18, 1906, reported that, although the shocks in the Imperial Valley earthquake were of shorter duration, they were sharper and more violent.

SOUNDS ACCOMPANYING THE SHOCKS

In none of the earthquakes previously studied by the writer have the sounds that preceded or accompanied the shocks been very noticeable. The Imperial Valley earthquakes, however, were preceded by a roar that was not only noticeable but it was heard by nearly everyone in the valley at the time. Indeed the rumble was heard before the shock was felt throughout an area of which the IV isoseismal is an approximate boundary, or over an area of approximately 10,000 square miles. It seemed to be exceptionally loud within the VI isoseismal, where about ninety-nine percent of the inhabitants heard it. This is one of the features about the shocks that inspired the most

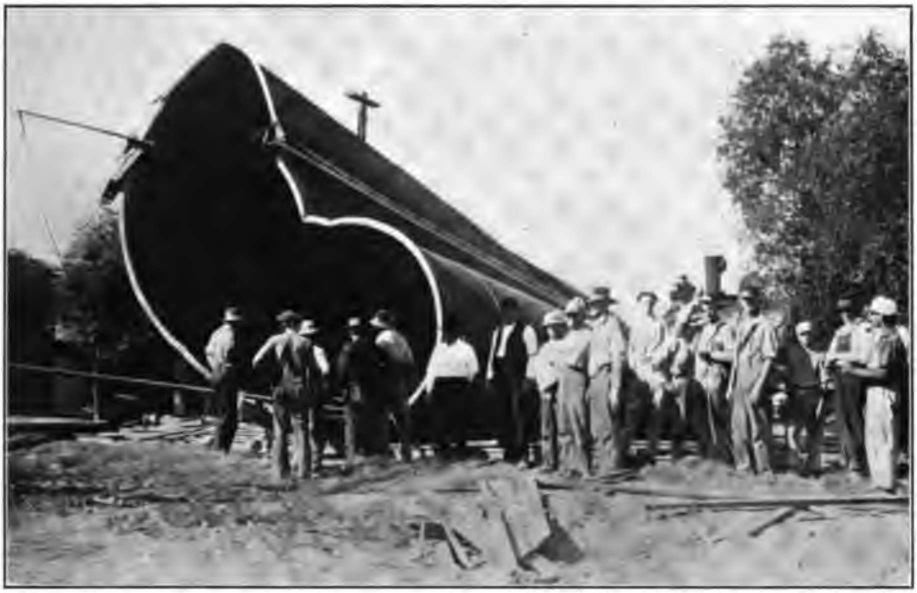

Fig. 11. Water tank of the Southern Pacific Railroad Company, at Calexico, California, overthrown by the earthquake of June 22, 1915.

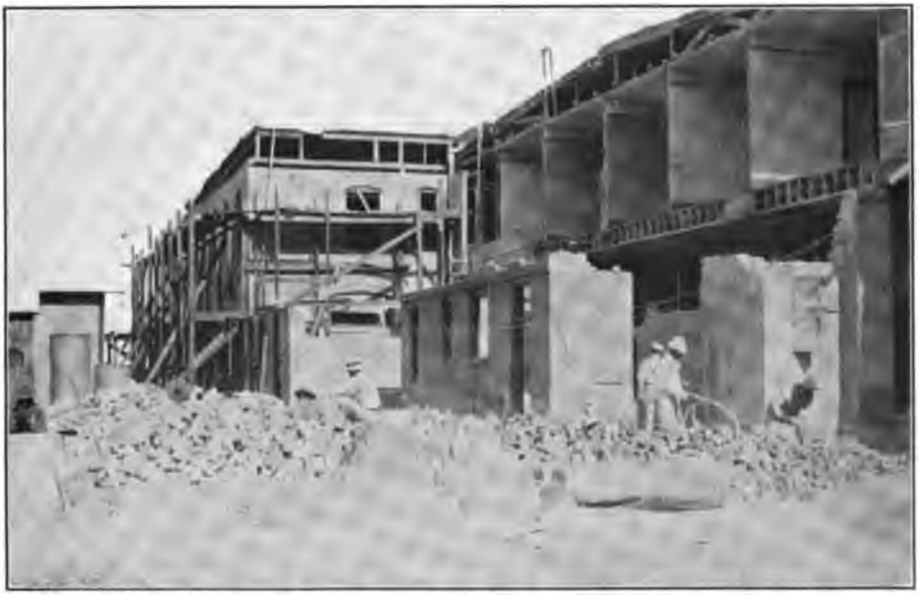

Fig. 12. The side of Hotel Calexico, at Calexico, California, after the earthquake of June 22, 1915.

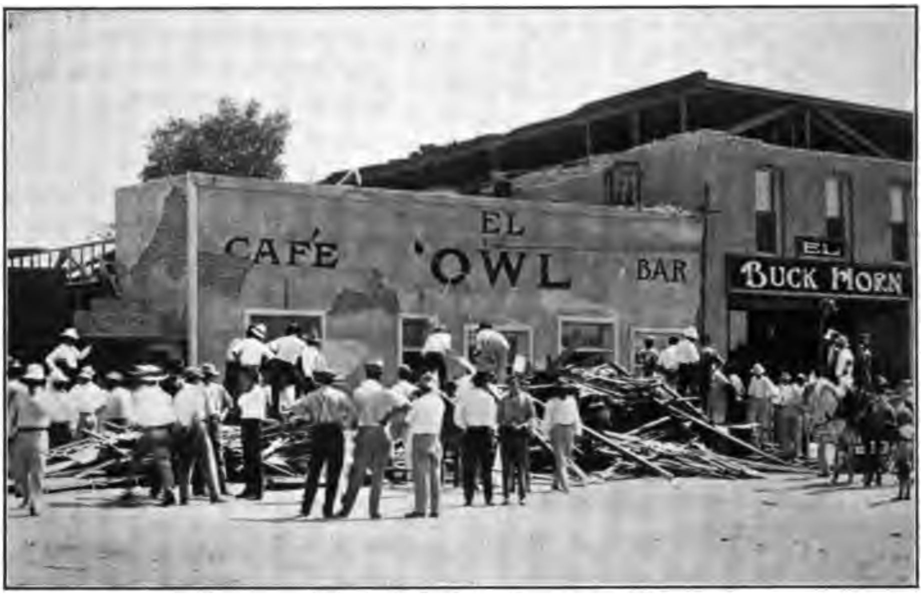

Fig. 13. Results of the earthquake in Mexicali, Lower California. Six people were killed and many were injured at this locality.

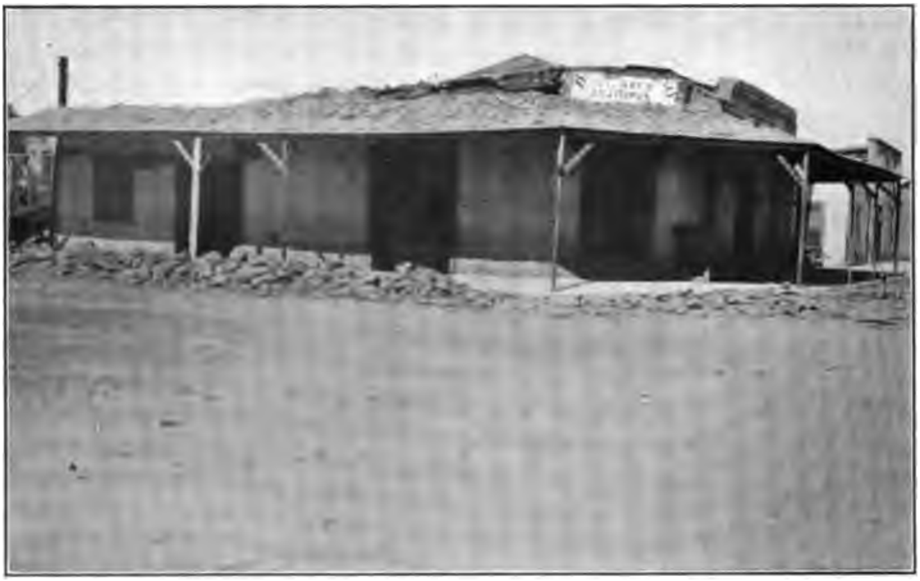

Fig. 14. An adobe building in Mexicali, Lower California, after the earthquake. The thick adobe walls withstood the shock better than the brick walls of neighboring buildings.

fear. Nearly all of the after-shocks were preceded by this kind of noise, which was heard practically wherever the shock was felt.

The rumble preceded the two heavy shocks by one or two seconds —some say five—and could be heard coming across the desert, or, as some described it, from beneath their very feet; while a number of people living near the IV isoseismal reported that the rumble accompanied the shock.

The noise was described as being similar to distant thunder, and by some is said to have resembled a loud clap of thunder. Many say it sounded like distant, heavy blasting, while others claim that it began with an almost inaudible murmur and increased to a loud crash.

The Shocks

The shocks that caused the disturbance in the Imperial Valley are of the simple type according to C. Davison's[4] classification of earthquake shocks. It was due to slipping along a fault plane, from which originated sets of simple vibrations lasting only a few seconds each and having but a single maximum of intensity.

The first shock was a series of backward and forward jerks lasting but a few seconds, cracking walls, overturning chimneys, and throwing much material from the shelves in the stores and shops. One observer stated that he thought a wheel had come off the automobile in which he was riding. Another person said it seemed as though his house were being hauled on a wagon over a rough road.

The second earthquake was a little more severe, and is described as being more of a twisting jerk. This also had but one maximum of intensity, and is classed as a simple earthquake. The movement of the first shock was largely horizontal, while that of the last was partly vertical. One person stated that he first heard a noise like a clap of thunder, then felt a tremor followed by a terrific shock which decreased in intensity to another tremor.

Direction

Careful inquiry was made in regard to the direction of the earthquake shocks at various localities, and it was found that very little dependence could be placed on the personal observations of the direction of an earthquake shock. The people in the northwestern part of the valley who live within a few miles of the Superstition Mountains declared that the shocks and the rumble preceding the shocks came from those hills; and a few, south of the international boundary, who hold Cerro Prieto in awe, claimed that the disturbance came from there.

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[4] Davison, C.: The Origin of Earthquakes. G. P. Putnam's Sons, New York, 1912.

Ninety-one percent of the people consulted who live within the V isoseismal experienced, or thought they experienced, a direction to the shocks; while fifty-five percent claimed that the roar preceding the shocks and the shocks came from the point ultimately decided upon by the writer as the epicenter.

AFTER-SHOCKS

For a few hours after the severe shocks on the night of June 22d the ground was almost constantly in motion with the customary series of after-shocks which follows nearly every earthquake of any importance. The frequency of the shocks rapidly decreased, however, but they have been felt almost daily up to the present time, and practically all of them are preceded by a dull rumble. Occasionally a rumble is heard without an accompanying shock.

One of the most severe after-shocks occurred on the evening of July 3d, and was apparently more distinctly felt north and west of El Centro than elsewhere. From the information obtained, the July 3d earthquake must have attained an intensity of about VI. This shock was followed during the night by over two hundred tremors, which occurred every few minutes. None of these tremors following the after-shock of July 3d were felt in the southern part of the valley, and the main shock is thought to have originated either on the San Jacinto fault in the Superstition Mountains or on the doubtful fault running northwest and southeast through the Salton Sea.

On August 18th at about 2:40 p.m. and 8:00 p.m. two severe after-shocks, probably approaching an intensity of V, were felt in the southern part of the valley; and on the following day, at about the same times, two more of about the same intensity were felt. El Centro experienced another after-shock on August 25th at 7:00 a.m. This was not severe, but of considerable duration. On the same day a light earthquake was felt in Calexico also.

ACKNOWLEDGMENTS

The writer is indebted to President J. C. Branner, of Stanford University, who directed the work of the expedition; to Mr. E. W. Dunlap, who ably assisted in the first part of the work; and to Mr. J. B. Lippencott and Mr. Hyde Forbes, who furnished geologic data relative to the San Jacinto fault. Señor Estaban Cantú, Military Governor of Lower California, gave sufficient guarantees of safety to

permit the writer to travel through the northern part of Lower California. Special mention should be made of the courtesy shown and the aid given by those in charge of the Abbott Ranch in Lower California, and of the Cort family in the Coahuilla Valley, who were very hospitable and placed every possible convenience at the disposal of the writer. Mr. Charles N. Perry, county surveyor of Imperial county, furnished valuable maps and information; and Mr. J. A. Taff, geologist for the Southern Pacific Company, made available certain data on the geology of the region along the eastern base of the San Jacinto Mountains.

A PROBLEM IN SEISMOLOGICAL GEOLOGY: ON THE SEISMOGENIC INFLUENCE OF PARALLEL SHELF-FAULTS

By COUNT DE MONTESSUS DE BALLORE.

Editor's note.—In the following paper the writer distinguishes the greater seismic activity of recently folded regions such as the Alps from the lesser activity of regions of broad epeirogenic uplift, such as Germany. In areas of the latter class he recognizes the occurrence of depressed zones, bounded by parallel faults ("shelf-faults"), and he states that such zones are districts of seismic activity of marked intensity though in less degree than the folded regions. He designates such down-faulted zones "rabbets."

Two examples are discussed: The rabbet of the Rhine between Basel and Mainz, which is contrasted with the Alps and the Rhine valley north of Mainz. And second, the rabbet of Erythrea, extending through Palestine and Arabia. This fault valley the author divides into three sections, of which the northern, being related to a folded zone, is of greater seismic activity; the central is active, but not in so high a degree; and the southern, comprising Arabia and Egypt, is relatively inactive.

One of the most important results lately attained in seismological geology is that regions recently (in the geological sense of the word) subjected to negative orogenic movements, or upthrusts in the midst of a geosyncline, are much more unstable than the ones which have been the theatre of epeirogenetic movements. But in regard to the seismicity of the latter, we know almost nothing more, and we take the opportunity of showing that in two cases at least, namely in the Erythrean and Rhenan (the Rhine) rabbets, or grooves,[1] the existence of parallel shelf-faults, between which terrestrial blocks have been let down, has the greater influence upon the geographic distribution of earthquakes.

The Erythrean rabbet is unquestionably the most extraordinary feature on the earth's surface. It stretches in an almost meridianal direction between the Orontes and Zambeze valleys, a distance of six thousand kilometers. It seems as if mysterious forces had threatened to break the planet in two, and that the catastrophe had begun to be accomplished.

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[1] Contrary to the accepted usage, we prefer the words rabbet or groove, to those of ditch, foss or "Graben" (this latter a German one, now frequently employed by geologists), for the inner sides of a rabbet are perpendicular to the board into which it is hollowed, while those of a ditch can be either vertical or inclined. The walls of the Erythrean and Rhenan depressions are bounded by vertical or almost vertical splits, clefts or rifts, as the former have often been named. On the contrary, the word rift is very appropriate for the California fault extending from Cape Mendocino to the Mohave Desert.

The part of the rabbet we shall speak of is the one starting north of the Orontes valley and extending to the Strait of Bab-el-Mandeb. Its successive segments are the following: the Coelesyria depression

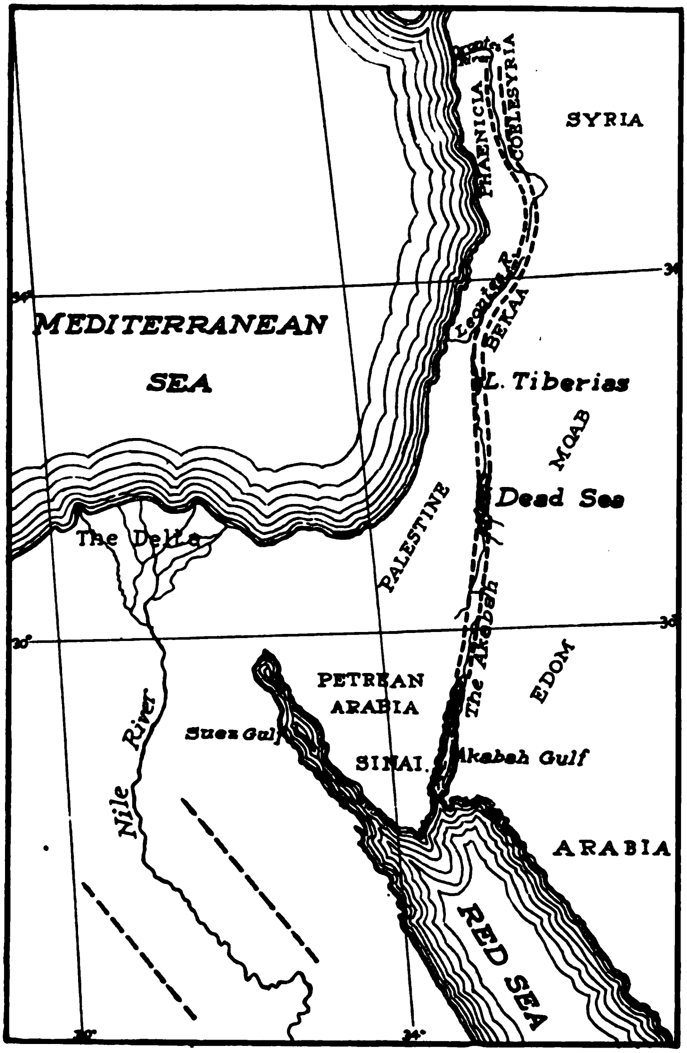

Fig 1. Map of the Erythrean rabbet or groove.

in Syria and the Bekaa between the Lebanon and Antilebanon ranges; the Jordan valley, with the umbilicus of Tiberias lake; the Dead Sea, with its extraordinary depth below the general oceanic level; the Arabah furrow carved into the Arabian Petraea and Edom highlands; the Akabah and Suez gulfs on either side of the Sinaitic pier; the Red (or Erythrean) Sea between Arabia and Egypt, with the secondary and parallel furrow of the low Nile valley, both carved between the massive tablelands of the Arabian and Lybian deserts.

The work of Lartet, Blankenhorn, Hull, Diener and other geologists shows that this narrow and profound northern part of the rabbet, with its irregular bottom, has been formed between parallel faults, which have opened into a vast area uplifted at the end of the Tertiary and at the beginning of the Quaternary era in consequence of epeirogenic movements. It is noteworthy, however, that these movements were not accompanied by folding even in the Lebanon and Antilebanon ranges.

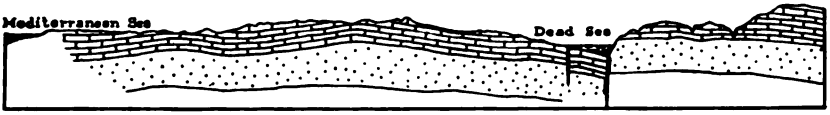

Fig. 2. Geologic section through the Dead Sea. (After Lartet. Exploration Géologique La Mer Morte de la Palestine et de L'Idumée. Paris 1887.)

The main geological features appear in three different forms, according as we consider its northern (Coelesyria, Bekaa), middle (Jordan valley, Dead Sea), or its entire southern part. In the first area we find parallel shelf-faults on each side of the rabbet, as well as at the west and east sides of the Lebanon and Anti-lebanon salient swellings respectively; in the second area there are parallel shelf-faults only on the western side of the axis of the rabbet and as far as the Mediterranean coast; in the third area this geomorphogenical structure disappears completely. The first area is an anticlinal arch, the second is a monoclinal "flexure", both broken away, and the third is a horizontal highland.

The disastrous earthquakes of Antioch and Aleppo are famous in history, but, in as much as it is transverse to the Erythrean rabbet, the inferior Orontes valley does not belong to it; and besides, this latter relief feature is due to the orogenic folding movements which raised the Taunus Range on top of the Alpine-Himalayan geosyncline, whilst the former has become an area of epeirogenic movements.

Let us now describe the successive segments of the rabbet, as they have already been defined, according as they are subject or not subject to earthquakes. All of its northern part is subject to destructive earthquakes, but they are far from being as serious as those felt at Antioch and Aleppo, showing once more the greater seismicity of the folding areas as to that of the epeirogenic ones. These earthquakes threaten not only the rabbet itself, but also Phoenicia and Syria, the adjacent territory on the east and the west. Though the middle part, Palestine and Moab, has had some destructive earthquakes in historical times, these phenomena have been very much less frequent than in the first part; moreover, we know of only one for the Moab, that of Areopolis. The southern part, Arabia and Egypt, is quite free from seismic disturbances.

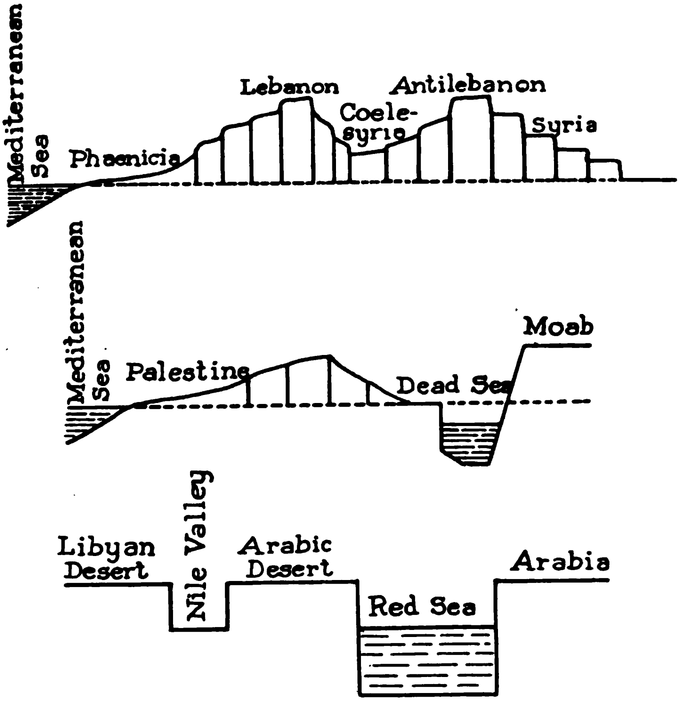

Fig. 3. Schematic sections of the Erythrean rabbet or groove by the author.

This latter affirmation regarding Egypt does not agree with the opinion of some seismologists; we are therefore compelled to develop more our own assertion.

For lack of sufficient knowledge of African seismic phenomena, in our "Géographie Séismologique" we have assumed the perfect aseismicity of all the Red Sea outlines. It was an error, for at Massawah, or in the Italian Erythrean colony, there is a seismic zone; but it is very narrow and, besides, it seems to belong to the seismic region of Abyssinian folds. So its existence does not alter or disturb in any way the general aseismicity of the lands of epeirogenetic structure across which has been opened this eastern "channel" in consequence of a gigantic subsidence at the end of Tertiary times or the beginning of the Quaternary, or of the Pleistocene period.

As regards Egypt, in spite of the extraordinary antiquity of its hieroglyphic annals and of our knowledge of its history from classic to modern times, we know of no disastrous earthquake in that country, though we do know of some sharp shocks which were barely strong enough to crack or throw down some old walls. Without doubt Alexandria has suffered sometimes in consequence of violent sea-waves, but they proceeded from seismic phenomena which had their origin either in Grecian lands and seas or in Asia Minor. Such waves have not been observed on the Red Sea coasts. However, in their great earthquake catalogue, the Mallet brothers have mentioned some great Egyptian earthquakes on the authority of Jelal-el-Din-As-Soyute (cf. Sprenger; Jl. As. Soc. Bengal, XII (n. 141, N. S., n. 67,741. 1843). But this Arabian traveler and chronologist has reported destructive earthquakes without giving either the months or days of the events or even the names of the cities damaged, so that the facts evidently lack authenticity.

Upon the whole, it is proved by the geographical distribution of seismic disturbances along the Erythrean rabbet from Orontes valley to the Bab-el-Mandeb strait that:

First—Elevations which have originated from orogenic movements of folding are more liable to great earthquakes than those which have proceeded from epeirogenic movements.

Second—In these latter regions the intensity and frequency of destructive earthquakes are related to the parallel shelf-faults according as they are or are not concomitant to the rabbet.

The first observation is well known; the second is new.

Identical circumstances occur in the Rhenan rabbet between Basel and Mainz, which has been deepened by the subsidence of the axis of an anticline (the Vosges and the Black Forest) between parallel shelf-faults, as it has been observed by many geologists. To the south the region of the Alpine folds of Switzerland is seismically more unstable than the portion of the Rhenan rabbet above alluded to; and, in its turn, this latter geographical feature is disturbed by earthquakes more than the valley north of Mainz, where there are no faults of this kind.

SEISMOLOGICAL NOTES

Distant earthquake, May 1, 1915.—A distant shock was recorded at several seismologic stations in the United States on May 1st. Reports show that it was recorded in England at Stonyhurst College; in Portugal at Coimbra; in Spain at Barcelona and Granada; in China at Shanghai; in Canada at Ottawa; in the United States at Cambridge, Mass., Denver, Colo., Santa Clara, Cal., Georgetown, D. C., and Cleveland, Ohio. The Harvard station locates the centrum in the Kurile Islands with a question.

Munich, Germany, June 3, 1915.—The press dispatches report an earthquake at Munich of sufficient violence to wreck some of the instruments in the observatory tower. There was much alarm, but no other damage is reported.

Bay of San Francisco, Cal., June 6, 1915.—A shock having an intensity of IV and below was generally felt between 9:46 and 10:51:31 a.m. on June 6th in the towns about the Bay of San Francisco. At Stanford University Professor G. H. Marx, who was in his office on the second floor of the engineering building, noted the rattling of windows at 9:46.

At the Chabot observatory in Oakland Mr. Charles Burckhalter notes that the time was 10:51:31 a.m., the intensity IV, Rossi-Forel scale, that there was a single shock lasting only two seconds, and that it resembled an explosion.

At Sausalito Mr. T. H. Claussen noted that the shock resembled a sharp jolt followed after a second or two by a gentle trembling. Windows rattled, and some cats playing on an adjoining building were disturbed.

At 1800 Broadway, San Francisco, Dr. Horace Davis noted one short sharp bump lasting only a second or two.

The following reports were kindly furnished by the engineers of the Spring Valley Water Company of San Francisco: At University Mound station in the southern part of the city the shock was slight, but was accompanied by a rumbling noise. At Lake Honda the time was recorded at 9:52 a.m., and accompanied by a rumbling sound. At Lombard Street no sound was observed. At Millbrae, Cal., the time was 9:50 a.m., and the shock is said to have lasted three or four seconds. Windows rattled, and the shock was generally felt; no sounds were observed. At San Andreas lake the time was 9:50 a.m.; the shock is said to have lasted four seconds and to have been accompanied by a low rumbling noise. At Pilarcitos west of San Mateo the time was 9:50, it is said to have lasted three seconds, and was accompanied by a rumbling sound. At the Lower Crystal Springs station west of Belmont the rumbling was noted. Nowhere was any damage reported from this shock, nor have we sufficient data to locate the epicenter.

Würtemberg, Germany, June 13, 1915.—A severe earthquake is reported from the kingdom of Würtemberg, Germany, especially in the towns of Ebingen and Balingen.

Eruption of Katmai, Alaska, June 17, 1915.—Incoming steamers report an eruption of Katmai on June 17th. The falling ashes compelled vessels to anchor on the north side of Kadiak Island from four o'clock until nine at night.

Tokio, Japan, June 20, 1915.—Press dispatches tell of an earthquake damaging a number of houses in Tokyo on June 20th. This shock was felt over a large area in central Japan, and is said to have been one of the severest felt for several years.

A submarine eruption was reported at 8:30 a.m. on June 19th about 150 miles south of Yokohama.

Imperial Valley, Cal., June 22, 1915.—The Imperial Valley earthquake is described at length by Mr. Carl H. Beal in this number of the BULLETIN.

Panama, June 26-28, 1915.—Press dispatches mention without details an earthquake at Panama on June 26th that caused a landslide in the canal, and another on the 28th.

Island of Kiushiu, Japan, July 14-16, 1915.—Press dispatches report earthquakes on the southern part of the Island of Kiushiu. The shocks occurred about every half hour for two days. Eruptions of the volcano Kirishima were increasing in violence.

Mount Hamilton, Cal., July 19, 1915.—An earthquake on July 19th at Mount Hamilton was felt by several persons and the intensity estimated at III to IV, R.-F. scale. The time was 3:10:30 p.m., P. S. T.

Laibach, Austria, August 11, 1915.—An earthquake of unusual severity was felt at Laibach, Austria, August 11th. The most violent shock occurred at 10:14 a.m. These disturbances are said to have been felt through southern Italy also.

Italian volcanoes active.—In August, 1915, Vesuvius, Aetna, and Stromboli renewed their activities. Lava flowed down the eastern slope of Aetna and threatened several villages of Sicily. Earthquakes have also been felt in Brindisi and Tarante.

British Columbia, August 18, 1915.—At 6:06 a.m. on August 18th an earthquake was felt over nearly all of British Columbia lasting in some places twenty seconds or more. It was reported from Vancouver, Yale, Harrison, Penticton, and Summerland. It was also observed at Seattle, Wash., and at Bellingham where doors and windows rattled and sleepers awakened. No damage was done.

Ecuador, August 22, 1915.—Shortly after four o'clock a.m., August 22d, an earthquake shock was felt at Quito, Ecuador, strong enough to cause a general panic. At Latacunga also the shock was a strong one and the people were greatly alarmed. The astronomical observatory at Quito reports that the shock there was registered at 4:13:16 a.m., and that it was one of the strongest felt at that place for a long time. It was concluded that the shock was local. Reports from other places show that the highest intensity was in the province of Pichincha, that it was lighter in Imbabura and Leon, and that it was not felt on the coast.

Hill Camp, Santa Maria Oilfield, Cal.—August 23, 1915, a slight shock was felt at 3:15 p.m. August 31st, a short tremble felt between 1:00 and 2:00 p.m. September 14th, a "heavy roller" was felt, composed of three hard shocks, the duration not being known; the earth trembled for fifteen minutes afterwards.

Avezzano, Italy, August 28, 1915.—Several earthquake shocks were felt at Avezzano during the day, but no damage was done.

Jutiapa, Guatemala, September 7, 1915.—A strong earthquake occurred in Central America, September 7th, and was felt over a large area in Guatemala and San Salvador. Jutiapa, a town of some 12,000 inhabitants, is said to have been left in ruins, and the churches in Santa Ana, Sononote, and in several other villages are reported destroyed. The shock was severe in Costa Rica, and the submarine cable on the Costa Rica coast is said to have been damaged.

This earthquake appears to have been felt in Mexico, in Canada, in the eastern United States, and even in Scotland.

San Luis Obispo, Cal., September 8, 1915.—A shock was felt about 4:45 a.m. on September 8th at the places mentioned below. The engineer on the pipe line at Antelope said it made the building rattle. It shook the water well so much that oil came out with the water. There were two distinct shocks, the first being heavier and lasting four or five seconds.

At Shandon an engineer sitting in a chair thought the fireman was behind shaking him. It did not knock anything down or stop the clock. The telephone operator at Paso Robles felt it. The pipe line engineer at Creston said the movement was short and sharp. At Port San Luis there was a short, sharp shock. A slight landslide occurred there. It was not felt at Orcutt or at Hill Camp.

Roy E. Collom.

Rome, Italy, September 23, 1915.—A slight shock was felt at 7:15 p.m. at Rome. It was more severe, however, in other parts of Italy, and caused some damage. At Agualia fifty-eight miles northeast of Rome it caused considerable alarm.

Messina, September 24, 1915.—A strong shock was felt at 9:15 p.m. at Messina. No damage was done, but the people were greatly alarmed and many passed the night in the open.

Central California, October 1, 1915.—An earthquake was felt at 7:26 a.m. by nearly everyone at Stanford University and in the town of Palo Alto, a mile away. Windows and furniture rattled, and the timbers of houses creaked. The shock lasted from three to five seconds; intensity III to IV R.-F. scale. This shock was also felt at Sausalito, just north of San Francisco. Mr. Leonard L. Hohl of Sausalito reports that two persons talking over the telephone at the time of the shock observed that it was felt about one second later one mile east of Sausalito, showing that it originated west of that town, possibly at or near the San Andreas fault line.

The Spring Valley Water Company reports this shock from its Lombard Street residence in San Francisco, from Crystal Springs Cottage on the east side of Crystal Springs Lake, from San Andreas Lake, and at the Pilarcitos station. Nowhere was the intensity thought to exceed IV R.-F. scale.

The earthquake of October 1, 1915.—The first waves of this earthquake arrived at the Lick Observatory at 7:26:25.6 a.m. The main phase began at 7:26:34.7. The maximum movement in the east-west component occurred at 7:26:36 and had an amplitude of 27 microns, with a period somewhat less than half a second. The maximum movement in the north-south component occurred at 7:26:38, and had an amplitude of 29 microns and a period a trifle less than half a second. Perceptible movement of the ground continued until 7:28:10.

The driving clock on the vertical seismograph stopped during the night before the earthquake, so no record of this shock was obtained on the vertical seismograph.

At Berkeley the earthquake was felt by the greater proportion of the inhabitants. The earthquake was accompanied by a rapid quivering of buildings. During this movement observers noted from one to three sudden jerks. A few persons at rest at the time of this earthquake did not notice the movement. The intensity of this earthquake in Berkeley is estimated to have been between III and IV of the Rossi-Forel scale. The movement was strong enough to start the Marvin strong-motion seismograph, but on account of the very small amplitude no satisfactory record was obtained on this instrument.

At Berkeley the first movement of the ground occurred at 7:26:19.9. The main phase of the earthquake began at 7:26:25.5. Movement of the ground continued up to 7:29:23. The maximum movement in all components was contemporaneous with the arrival of the chief phase of the shock. In the east-west component the maximum amplitude was 26 microns, and the period was about ¼ second. In the north-south component the maximum had an amplitude of 32 microns and a period of about ¼ second. In the vertical component the maximum had an amplitude equal to at least 50 microns, with a period of about one second. The vertical record was limited on one side by the safety stop, so the complete amplitude was not recorded.

The seismograms at this station showed a considerable amount of "tangling of the waves." This effect was especially noticeable on the east-west component..

The direction of the first shift of the ground in this earthquake could not be determined on the east-west and on the vertical component records. On the north-south component seismogram it was shown to be south. Since the origin lies to the south of this station, this earthquake apparently began with a wave of contraction.

The distance of the origin of this earthquake was estimated to be 44 miles from Mount Hamilton and 27 miles from the Berkeley Station. If circles be drawn with these radii and the proper stations as centers their intersections will be found to lie on the San Andreas Rift a little north of Redwood City, and near the town of Clayton. No earthquake was reported from Clayton. The intensity of this earthquake at points on the San Francisco peninsula indicates that the intersection on the San Andreas rift lies near the origin of this earthquake.

It was estimated that this earthquake occurred at the origin at 7:26:13.5±0.6.

E. F. DAVIS.

Seismographic Station, University of California,
Berkeley, Cal.

October 2, 1915.—A slight shock was felt at 1:17 a.m. at the Spring Valley House on the east side of Crystal Springs Lake, October 2d. The intensity was about III, and it lasted only about three seconds. The same shock was felt by several persons near Redwood and between there and Burlingame, Cal.

The Spring Valley Water Company report it from their Pilarcitos station, where it is said to have had an intensity of II.

Wasatch Mountains, October 2, 1915.—At least three sharp earthquake shocks were felt the night of October 2, 1915, in Utah, Idaho and Nevada. No damage was done, though the shock was violent enough to put out of service the seismograph of the Universtiy of Utah, at Salt Lake City.

Yosemite Valley, California, October 2, 1915.—A report kindly sent by Mr. O. L. Stephenson states that an earthquake was felt in the Yosemite at 10:50 p.m. on October 2d. No damage was done, but the movement seems to have been unusually long.

Kennedy, Nevada, October 2, 1915.—A report published in one of the San Francisco papers states that "every building in the mining town of Kennedy, Humboldt county, was destroyed by Saturday night's earthquake." We have not succeeded in verifying this statement.

Activity of Lassen Peak, California.—The earlier activities of Lassen Peak, Shasta county, California, have been described by Mr. J. S. Diller in this journal, volume IV, pp. 103 to 107, and in volume V, pp. 55-56, and 108. Explosions of gases and steam have continued spasmodically.

Going back to the explosions and floods of May 21, 1915, reports from the region state that Hat Creek, a stream on the north side of the mountain, overflowed its banks and swept down over its entire floodplain a vast sheet of muddy waters and left farms buried in from one to three feet of mud. For the first time flames are said to have issued from near the summit of the peak about midnight, and black clouds rose to a great height. The flood began about four o'clock a.m. on the 21st and lasted until about one o'clock in the afternoon. Bridges were washed away, roads rendered impassable, and buildings swept from their foundations. The people living in Hat Creek valley all fled. The ashes from the explosions were carried eastward more than 200 miles and fell in considerable quantities near Winnemucca, Nevada.

The mud carried down by Hat Creek is often spoken of as lava, but later examinations by A. L. Day and J. S. Diller show that it was only the cinders washed down by the floods produced by the melting of snow and ice near the top of the peak.

This outburst is said to have been preceded by an earthquake that rattled windows but did no damage. It was especially noticeable at Burney.

The great explosion near the summit of the peak knocked down all the trees along a sector leading away from the mountain. The trees were left lying flat on the ground with their tops pointing away from the peak as if they had been overthrown by a single blast.

On May 23d the mountain was still concealed by clouds. On the 25th the clouds lifted, and the settlers began returning to Hat

Creek valley. The returning settlers found that the water of Hat Creek was still too muddy to be used, and water had to be hauled in a distance of six miles.

Professor R. S. Holway of the University of California ascended the peak May 27th and was led to conclude that the bottom of the old crater had been pushed bodily upward by pressure from below, and left filled with jagged rocks from which steam is escaping. The northern rim of the old crater is broken and changed. He was convinced that the mud of the Hat Creek flood did not flow from the crater.

On May 30th the peak renewed its activity somewhat by throwing out ashes and sending a column of smoke high in the air. Vast quantities of ashes drifted northward and eastward. A new crater is said to have been formed four hundred feet below the former one.

Nothing worthy of note occurred again until June 16th, when a great column of smoke rose from the summit. Again on June 25th smoke arose from the north side of the crater and continued on June 26th and 27th.

The next noteworthy manifestation was July 13th, when rumblings were heard by the inhabitants of the Hat Creek region. Similar rumblings were heard on July 27th. Only a small eruption was observed August 6th. On September 9th a pillar of smoke arose again from the summit, and ashes fell at the town of Mineral. September 23d there were clouds of black smoke again.

The period of activity of the volcano seems to have culminated on May 21st. Since then it has subsided and has indeed almost ceased its activity.

An interesting account, "When Lassen Wakes," is published by Professor R. S. Holway in the *Sunset Magazine* for August, 1915, pages 263-269.

REVIEWS

REFLECTION AND REFRACTION OF ELASTIC WAVES, WITH SEISMOLOGICAL APPLICATION. By C. G. Knott. *Phil. Mag.*, 48-64.

After a theoretical investigation, the result of which is the assertion that a single transverse or longitudinal wave in an elastic solid will, in general, upon reflection produce *both* a transverse and a longitudinal wave and that the same is true in the case of refraction, the author makes the following statement:

"In the light of these results, then, it is little wonder that no definite relation has ever been shown to exist between the manner of motion of a particle and the direction of propagation of an earthquake. I should also be inclined to regard as absolutely futile any attempt to infer the nature of the movement in which the shock originates from the nature of the motion of any surface particle."

F. J. ROGERS.

PHILIPPINE EARTHQUAKES. In the *Bulletin of the Weather Bureau,* Manila Central Observatory, for December, 1913, pp. 386-388, is published a tabulation of Philippine earthquakes for the year 1913. The table embraces columns giving date, time of occurrence, place, probable origin or epicenter, approximate extensions of the shaken area, intensity (R-F), and remarks. One hundred and forty-eight shocks, well distributed throughout the year, and varying in intensity from III to VIII-IX, are definitely recorded. Of these, 67 had an intensity recorded at III, 11 at III-IV, 36 at IV, 8 at IV-V, 14 at V, 2 at V-VI, 3 at VI, 1 at VI-VII, 3 at VII, and 1 each at VII-VIII, VIII, and VIII-IX. In addition to the definitely recorded shocks many of the earthquakes were followed by numerous after-shocks of varying intensities. A few were also preceded by shocks of less intensity. The heavier shocks occurred principally in the islands of Luzon and Mindanao.

E. C. TEMPLETON.

THE REGISTRATION OF EARTHQUAKES AT THE BERKELEY STATION AND AT THE LICK OBSERVATORY STATION from October 1, 1914, to March 31, 1915. By E. F. Davis. *Univ. of Calif. Pub., Bull. Seis. Stations*, No. 9, pp. 169-188 (August 9, 1915).

During the period covered by this bulletin 22 earthquakes were recorded by the Berkeley Station and 42 by the Lick Observatory Station. A larger number of earthquakes was recorded at the Lick Observatory Station than at the Berkeley Station because of the fact that Mount Hamilton was near the place of origin of a considerable number of weak local shocks. These were generally of slight intensity and did not involve sufficient energy to permit their registration as far away as Berkeley.

Several earthquakes are discussed in detail in the text of this report. The West Indian earthquake, originating in the neighborhood of Martinique and St. Vincent, on October 3, 1914, was recorded at both stations and is discussed in the text of the report. The Italian earthquake, originating near Avezzano, on January 13, 1915, was also recorded at both stations. Characteristic phases were not very well defined on the seismograms, but the time of arrival of the chief phase indicates that these records were those of the Italian earthquake. The seismograms of one other distant earthquake are discussed. The place of origin of this earthquake is not stated. It occurred on November 24, 1914.

Several California earthquakes are given special discussion in the text. Among these are the earthquake of November 8, 1914, in Southern California; the Central California earthquake of November 8, 1914, originating on the San Andreas Rift near Laurel, California; the Central California earthquake of November 21, 1914; and the Southern California earthquake of January 12, 1915, originating near Los Alamos.

One item of interest is the statement that the Berkeley Station has installed a set of Galitzin prisms for the determination of earthquake intensity. These prisms are set up in the seismograph room and it is planned to check their performance against the seismographic records. A very brief description of these prisms is given in this report, together with a reference to Galitzin's original article.

E. F. DAVIS.

PUBLICATIONS OF ST. LOUIS UNIVERSITY, vol. X, no. 1, *Bulletin of the Geophysical Observatory*, April 1914.

In this publication, under the heading "On the Epicenter Problem," is presented a method for the rapid approximate location of earthquake epicenters by means of specially constructed "Time-Difference Charts." Given the correct arrival times of the preliminary tremors at three observation stations properly spaced to give adequate base lines, and assuming the Wiechert and Zoeppritz (W. & Z.) curve to be a correct expression of the rate of travel of these tremors, the location of the epicenter resolves itself into a problem in spherical trigonometry. The purpose of the charts is to afford a very rapid approximate graphical solution of this problem. Three charts, each based on a set of three observation stations (Hamburg-Vienna-Pulkowa, Berkeley-Ottawa-St. Louis, and Ottawa-St. Louis-New Orleans) accompany the paper. Similar charts can be compared without great difficulty for any set of three stations. Obviously any chart is applicable only to data from the three stations for which that particular chart was prepared. The article explains the theory, construction and use of the charts and gives a number of examples of their application in determining almost immediately the approximate locations of the epicenters of actual earthquakes.

A second section of the same article develops formulae for the location of earthquake epicenters, given the correct *S-P* (time interval between arrival of preliminary and secondary tremors) of any two stations and the fairly correct arrival times of the preliminary tremors at the three stations of a single chart.

E. C. TEMPLETON.

LOCATION OF EPICENTERS FOR 1914. By Otto Klotz. *Journal of the Royal Astronomical Society of Canada*, May-June 1915.

A tabulated list of epicenters of earthquakes of 1914, determined by comparing the records made at Ottawa with those from other stations, mostly European, is given in this report. By way of introduction the author makes the following rather significant remarks:

"In continuation of the series published annually since 1911, the located epicenters for the first half of the year 1914 are herewith issued. That we were able to determine only the epicenters up to July 1st last is due to the lamentable and insane war now raging in

Europe, in consequence of which no reports from the important earthquake stations in Europe have reached us since July; and unfortunately we have in America so very few stations that issue reports which give the necessary data desirable for the location of an epicenter. Harvard and Ottawa, so near each other, require data from distant stations, —say along the Pacific coast,—for seismic triangulation. The war emphasizes this requirement, and it is to be hoped it will bear fruit. The extent of America is great enough to make us, if necessary, independent of the rest of the world, provided we have the requisite stations, for locating any decent quake,—that is, a quake that shakes the world."

S. D. TOWNLEY.

SEISMOLOGY, TERRESTRIAL MAGNETISM AND GRAVITY. Report of the Chief Astronomer, 1911. By Otto Klotz, Ottawa.

This report, somewhat belated in publication, covers the period from April 1, 1910, to March 31, 1911.

Under the head of seismology the author states that the instruments in use during the period were: two Bosch photographic seismographs; a Callendar electric thermograph; a Shaw-Dines microbarograph; a Fuess electric anemograph; besides wet and dry bulb thermometers, the auxiliary instruments being used in the interpretation of seismograms. The only new instrument added during the year was the anemograph, of which the author gives a brief description.

There were eighty-nine earthquakes recorded by the instruments during the period under consideration, some of them being very severe disturbances at distant points. The author describes the process of interpreting a seismogram in order to find the distance of the disturbance, and then gives in some detail his method of locating the epicenter from observations obtained from three widely separated stations.

Some twenty pages of the report are given to the subject of microseisms, those small records made by the seismograph and now known not to be due to earthquakes. It is largely through the work of Dr. Klotz that the true interpretation of these records is now known. Those at Ottawa are due to ocean waves beating on the rocky shore of eastern Canada and the New England states. These waves are most pronounced when there is a barometric "low" with steep gradients on the ocean near the coast, for at that time the direction of the wind will be such as to set up heavy waves.

S. D. TOWNLEY.

CATALOGUE OF BOOKS AND PAPERS RELATING TO INTERNAL DYNAMICS OF THE EARTH, MAINLY FOR THE YEAR 1911. Published by the Royal Society of London: London 1914 (May), vii+54 pages.

This valuable catalogue is brought out by the International Association for Seismology. Copies of it can probably be had of the Royal Society of London, though no such statement is made in the pamphlet itself.

BIBLIOGRAFIA GENERAL DE TEMBLORES Y TERREMOTOS. Por F. de Montessus de Ballore. Primera parte: Teorias sismologicas, efectos geologicos de los Terremotos, Catalogos sismicos mundiales. Publicada por la Sociedad Chilena de Historia y Geografia. Roy. 8°, 115 pages; titles 1-644. Segunda parte: Europa Septentrionel y Central, pp. 117-253; titles 645-1560. Santiago de Chile, 1915.

By the publication of this bibliography the science of seismology is placed once more under profound obligations to Count Montessus de Ballore, the eminent author of so many of our most valuable works on seismology, and the actual director of the seismologic service of Chile. The work is a monumental one, completed under the extraordinary difficulties of the temporary inaccessibility of the great libraries of Europe and of the interruption of postal service by the European war.

Only two parts have been issued thus far; five more parts are yet to follow, and the total number of titles is expected to reach eight thousand.

In addition to the titles themselves the work contains many valuable annotations by the eminent author, made largely with a view to bringing out the evolution of the science. Papers confined to microseisms and the mathematics and mechanics of the subject are purposely omitted, and no effort is made to include the various editions of the books mentioned.

The price of subscription will be seventy francs if made before December 1915, or one hundred francs if made after that date. Subscriptions may be addressed to the Treasurer of the "Sociedad Chilena de Historia y Geografia," Santiago de Chile.

J. C. BRANNER.

THE CATASTROPHE OF AVEZZANO (January 13, 1915). By Manuel M. S. Navarro Neumann, S. J. *Revista de la Sociedad Astronomica,* Ano V, Enero-Febrero 1915, Num. 40.

Referring to the period of war through which we are now passing Father Neumann states that even the earth itself would seem to wish to participate in the work of destruction and is agitated with unusual violence now in one region and now in another, where it also sacrifices its victims.

In the last few months, the coast of the Mediterranean and its neighborhood, that is, the Mediterranean depression, has given proofs of great earthquake activity, and among them, without citing any other than the most destructive of the earthquakes registered in the seismological station of Cartuja (Granada), we may mention the following earthquakes: That of the third of October (1914), in the district of Konia, Asia Minor, with the epicentrum in 36.6° north and 30.2° east, Gr. (Cartuja 2,900 kms. and Hamburg 2,370); on the 17th of the same month the earthquake felt in almost all of Greece, which threw down a hundred houses in Tebas, occasioning many injuries (many houses cracked in Chalcis, violent in Athens, and panics in many places). On the 26th of the same month in Piedmont, Savoy and Liguria, with the greatest intensity west of Turin near Bussoleno, Giaveno and Rivoli. Also, on the 27th of October, the earthquake of Emilia, Romaña, Toscana, Lombardia, and Piedmont, with some victims and important damage in Lucca, Pescia and Pietrasanta; on the 27th of November with 23 victims, many wounded persons, and great damage in Leukas (the island of Santa Maura in Greece). While on the 13th of January of the present year, 1915, the neighborhood of Lake Fucino and the nearby valley of Liri have added with terrifying figures to the already excessive list. The writer suggests that the movement of the earthquakes toward the west may possibly be anticipated to continue, and that Spain may be visited by earthquake shocks in the not distant future.

That the catastrophe which has just annihilated Avezzano and surroundings, including the neighborhood of the basin of Liri, has not exceeded in number of victims the earthquake of Messina of the 28th of December, 1908. That fact has been due merely to the non-occurrence of any city of considerable population in the region, and yet, even so, the number of victims reaches the figure of 39,000, whereas in the other great disaster 100,000 persons perished. The population of Messina and of Reggio-Calabria being respectively at the time 150,000 and 50,000 without counting the populous suburbs.

In the city of Messina the mortality was 50% of the inhabitants. In that of Avezzano it rose to 82%, in San Benedetto to 88% and even to 90% in Goia dei Marsia,—figures which have never been exceeded in any earthquake.

The earthquake of Avezzano, as compared with that of San Francisco and that of Messina, did not produce great deviation of the seismograph at Cartuja (Granada). The San Francisco earthquake caused at Cartuja (distant 9,700 kilometers) a maximum deviation of the ground of 2 mm., and a maximum acceleration of 0.255 mm. per second, whereas that of Avezzano registered a deviation of scarcely a mm. (975μ 16^s) and the maximum acceleration corresponded to 0.475 mm. per second. The distance in this case was but 1560 kms. or but one-sixth of the other, and it is thus apparent that the San Francisco earthquake was at least twenty times as severe as that of Avezzano.

Similarly it appears that the Messina shock was more intense at Cartuja that that of Avezzano, in the proportion of 75μ to 65μ, although Avezzano was 130 kilometers nearer than Messina.

The earthquake of Avezzano was not, therefore, an exceptional shock, when considered simply as a movement of the earth; but we have learned by sad experience that in Italy, and also in Bulgaria, Greece and Turkey, the earthquakes which give medium records are destructive ones. That of Avezzano must from the point of view of destructiveness be considered a *megasismo,* but the writer finds the reason for the great mortality to lie largely in the manner of construction of the stone and brick buildings put together with miserable mortar. The photographs accompanying the article show that scarcely a stone remains upon another. Another condition which occasioned great mortality was the falling of the floors, even though the walls stood, the beams being too lightly stept into the walls.

Bailey Willis.

Report of the Observatory of Samoa for the Year 1913-14. By E. Wiechert. *XIII. Bericht über das Samoa-Observatorium für das Jahr 1913-14.*

During the year 1913-14 there has occurred in the affairs of the observatory of Samoa one important change and steps have been taken toward another. Dr. H. Wagner, who hitherto has been the

Director of the Observatory, has, on account of his great age, laid down the duties of Director and resigned from the corps of the institution. Thanks to his effort and to the good will of the officials of the government, the observatory had been placed upon a sound financial basis, and there remained only to adjust the organization of the personnel of the observatory to the new financial condition. The remaining members of the directorship included Dr. Schultz, Governor of Samoa and resident of Apia, and the two members in Göttingen, Messrs. E. Riecke and E. Wiechert. The Royal Society of the Sciences having agreed to the selection, Mr. C. Runge was added to the Board, and he has accepted. The new directorship took over the records on the 13th of December, 1913, and they were placed in the care of Dr. Wiechert in the Geophysical Institute of the University. The retirement of Dr. Wagner is deeply regretted, as the success of the observatory has been mainly due to his care and activity.

The second change which is necessary in the affairs of the University is to secure a scientific Director for the work for a longer period of years than has hitherto been possible. Circumstances have hitherto made it necessary to employ young students, who, as a rule, remained about two years in Samoa in connection with the University and then returned to Göttingen to work up their observations. Efforts to modify this plan resulted in the selection of Professor Angenheister, who has already served twice as observer in Samoa, and who has declared himself ready to devote his energies to the observatory as Director for a period of nine years.

The report of Dr. Wiechert, of which the preceding is an abstract, closes with a list of publications of the University, issued in the Nachrichten of the Royal Society of Science in Göttingen, as follows:

Von der wissenschaftlichen Arbeit des Observatoriums legen folgende Veröffentlichungen des Jahres 1913-14 ein erfreuliches Zeugnis ab:

G. Angenheister: Über die Fortpflanzungsgeschwindigkeit magnetischer Störungen und Pulsationen. Bericht über die magnetischen Schnellregistrierungen in Apia (Samoa), Batavia, Cheltenham und Tsingtau im September 1911.

G. Angenheister: Über die dreijährige Luftdruckschwankung und ihren Zusammenhang mit Polschwankungen.

K. Wegener: Temperatur und Regen in Samoa 1909 und 1910 in gedrängter graphischer Darstellung.

G. Angenheister: Die luftelektrischen Beobachtungen am Samoa-Observatorium 1912-13. Mit zwei Anhängen:

I. Luftelektrische Beobachtungen zur See.

II. Über die Zunahme der Intensität der Wellen der drahtlosen Telegraphie bei Sonnenuntergang.

BAILEY WILLIS.

SUBTERRANEAN SOUNDS HEARD IN THE WEST INDIES. In the Bulletin Semestriel de L'Observatoire Météorologique du Séminaire-Collège St. Martial, Port-au-Prince, Haiti, January-June 1914, are some interesting notes concerning the rumbling sound, popularly known as the "gouffre," which is heard frequently in the West Indies. There appears to be a difference of opinion as to its cause, some claiming that the sound is related to seismic disturbances.

Mr. Maxwell Hall, British government meteorologist at Jamaica, is authority for the following:

> In 1835, at the time of the eruption of Coseguina (a volcano on the west coast of Nicaragua), noises like those of a cannonade were heard at Jamaica, 700 English miles away.
>
> At the beginning of January 1907, before the great earthquake of January 14th of that year, similar noises were heard at Mandeville and in other parts of the parish of Manchester, and at certain places in the parish of St. Elizabeth. They were heard several times at the same places, and were mistaken for noises of distant thundering or of the firing of large caliber cannon.
>
> At 8:30 a.m., December 3, 1907, distinct rumblings were heard at Kings-Valley, Westmoreland. They seemed to come from a chain of high mountains to the north. No shock was felt.
>
> Noises like the sound of enormous waves on the shore were heard at Kings-Valley, Westmoreland, at 10 p.m., January 15, 1908. They came from the north, and lasted thirty or forty minutes.
>
> Rumblings from the north and northeast were heard at Kings-Valley, January 10, 1908, at 6:10 p.m.

The following notes from Môle St. Nicolas, Haiti, were contributed by the R. P. Simonneau:

> On January 20, 1914, at about 4:00 p.m., a noise of rumbling which seemed to come from the north and the northeast was heard at Môle. It was a clear day with but a moderate wind. The noise was repeated several times during the night until four o'clock in the morning. It sounded like the rolling of thunder, with hollow detonations repeated two, or even three times.

Sometimes it resembled the sound of waves dashing against the rocks. Nearly everybody heard these sounds, and on the next day, the 21st, it was understood at Môle that there was a revolution at Cap Haitien or somewhere in that region. * * * Some people thought these noises were the reverberation of cannon fired near Cap Haitien,—a thing which seemed impossible, since this was about 75 kilometers away. It is certain that during the night of January 20-21 no cannon were fired either at Cap Haitien or at Port de Paix.

On June 3d from 7:00 till 9:00 p.m. a number of people heard a rumbling noise to the north of Môle St. Nicolas and in the direction of Port de Paix. Seven or eight detonations at intervals of about ten minutes were heard, the noise resembling that of the firing of cannon, but without any reverberation, and lasting four or five seconds. It seemed to come from the sea.

At the Bay of Henne many people have frequently heard the rumbling sound. They regard it as the announcement of an earthquake, although more often than not no earthquake accompanies it.

Father J. B. Julio, curate at Pilate, states that

A hollow sound as of distant thunder was heard from time to time on the heights of Pilate between 4:00 and 9:00 a.m. on July 15th. The weather was calm and favorable to the distinct perception of this noise. To the observant this is merely the sound of waves which, rushing into the caverns of the sea of Borgne, produce the "gouffre," a noise which is echoed from mountain to mountain. But the people of Borgne maintain that it is produced in the sea by millions of little fishes

Mr. Y. Evenou, accountant of the Plantations of Haiti, sends the following notes from Bayeux:

The "gouffre" is well known in this vicinity. Often between the months of June and September it is mistaken for the sounds of distant storms in the bluffs. But sometimes when it is not stormy, and when the sky is clear, it is heard, like the muffled sound of cannon shot, regularly repeated as though it were the salute of a ship.

We ourselves have heard the sound and believed it to come from a battleship entering at Cap Haitien, when in reality there was no battleship there. Some people attribute the noise to the sea penetrating into the interior caverns of the earth; others think it due to falling bodies; some to the burning of gas within the earth. Without trying definitely to explain the phenomenon, the inhabitants appear to be very much impressed by it.

Notes from Canon L. M. Caze at Ganthier, Fonds-Verrette, describe

Certain gaping pits of great depth near Fonds-Verrette, Bois Tombé and Ravine Contreé from which strange sounds, as though produced by explosions, escape periodically at the approach of the rainy season of the year, and sometimes also during the dry season when strong winds are blowing. The explosions are said to be followed by the escape of great jets of a white vapor from the pits and to be accompanied by a violent trembling of the ground within a radius of 500 or 600 meters. There is evidently some superstition connected with these pits, since it is claimed that objects cast into the pit one day have been found on the following day lying on the ground near the pit's mouth.

E. C. TEMPLETON.

SEISMOLOGICAL REPORTS RECEIVED.

AMERICA

Denver, Colorado, Jesuit Seismological Service.—Reports nos. 2 to 8, from February 1, 1915 to August 31, 1915, including 5 bis and 6 bis.

Harvard University, Cambridge, Mass.—Record of the Seismographic Station, nos. 8-10 inclusive, May 1 to June 15, 1915.

University of Santa Clara, Cal., Jesuit Seismological Service.—Reports nos. 134 to 154 inclusive, from September 7, 1914, to August 6, 1915.

Ottawa, Canada, Earthquake Station, Dominion Astronomical Observatory.—Reports nos. 9 to 14, from June 1 to August 31, 1915.

ASIA

Zi-Ka-Wei, China.—Bulletin Sismique nos. 2 to 7, from February 4 to May 26, 1915.

EUROPE

Barcelona, Spain.—Estación Sismica de la Real Academia de Ciencias y Artes. Boletin Sismico nos. 1 to 15, from April 1, 1914 to June 30, 1915, including 2A, 5A, 7A and 14A.

Granada, Spain.—Estacíon Sismológica de Cartuja.—Boletin Mensual, nos. 4 to 6, April to June 1915.

Coimbra, Portugal, Observatorio Meteorologico, Magnetico e Sismico da Universidade.—Boletim Sismico, nos. 1A to 3B, from January 1 to May 3, 1915.

Stonyhurst College Observatory.—Earthquake Records from April 1 to June 29, 1915.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological Bulletins of the Observatory. Nos. 4 to 10, from February 1, to April 30, 1915.

MINUTES OF THE MEETINGS OF THE SEISMOLOGICAL SOCIETY OF AMERICA.

August 4 and 5, 1915.

In the absence of the President the meeting of August 4th was called to order by the Secretary at 2 p.m. in Room 320, Stanford University.

The President and Secretary were appointed to act as representatives of the Society in the matter of affiliation with the Pacific Branch of the American Association for the Advancement of Science.

Mr. Forest John S. Sur, of Calgary, Alberta, and Mr. A. C. Veatch, of London, England, were elected to membership in the Society, the election of the latter being to a life membership.

President McAdie's address, which is printed in this number of the BULLETIN, was read by the Secretary.

Dr. Bailey Willis presented an abstract of a paper by Count de Montessus de Ballore on "The Seismographic Influence of Parallel Shelf-Faults."

The program for the day was concluded with a talk by Dr. J. C. Branner on "Coöperation in Reporting Earthquake Data."

The meeting of August 5th was held at 2 p.m. in Room 203, Bacon Hall, University of California. A highly interesting paper was presented by Dr. Otto Klotz, of Ottawa. He gave an account of his recent work in the investigation of microseisms, showing a connection between these small earth movements and the state of the atmospheric pressure along the Atlantic seaboard. The undagraph, an instrument for recording the number of sea waves, was described by Dr. Klotz, and the action of one which he set up at Chebucto, near Halifax, was explained. A description of the undagraph was published in this BULLETIN, volume 3, page 20.

S. D. TOWNLEY, *Secretary.*

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

VI. **Fairly strong shock**: general awakening of those asleep, general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic. without damage to buildings.

VIII. **Very strong shock**: fall of chimneys. cracks in walls of buildings.

IX. **Extremely strong shock**: partial or total destruction of some buildings.

X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground. rock-falls from mountains.

The Bulletin of the
Seismological Society of America

VOL. V DECEMBER 1915 No. 4

DISCUSSION OF PRESIDENT McADIE'S ADDRESS

By W. F. Durand

The subject of the measurement of the forces acting in earthquake disturbance, as touched on in President McAdie's address, is one in which I have felt a keen interest since our experiences at Stanford University and vicinity in 1906. I have felt that there would be a marked advantage in some more direct measure of the disturbing force to which a given body is subjected, than that furnished by acceleration derived from a time-displacement curve, as furnished by the ordinary seismograph. Regarding this record we may fairly state two characteristics:

(1) We are not primarily concerned with the displacements and times as such, but rather with the accelerations which may be derived therefrom.

(2) All such records must be imperfect from the nature of the instrument. The latter assumes implicitly a tracing point remaining fixed in space while the record sheet is supposed to partake of the movements to be recorded; and the relative motion of the two constitutes the record as traced. The assumption that any point of the instrument will remain fixed while the record sheet oscillates with the earth is, however, only true to a degree; and the relative motion which is traced on the sheet must therefore contain components due to both motions. It follows that there is a resultant and inherent error in such records when viewed as a measure of the movements of a part of the earth relative to a point fixed in relation to the remainder.

It results from these considerations that an instrument which would read directly in terms of disturbing force would be preferable to the common displacement record. The problem is simple of statement, but I have thus far, in the desultory way in which I have been able to study the matter, found no satisfactory solution. The primary requirement is an instrument by means of which force, transformed into a pressure or pull, for instance, can be indicated or measured without relative movement between the parts subject to these forces.

fections of this instrument. The most serious obstacle to the rapid advance of technical seismology is the extreme difficulty of providing and maintaining instruments that appropriately respond to the demands that may be placed upon them.

U. S. Weather Bureau,
Washington, D. C.
August 7, 1915.

By Harry Fielding Reid

I have read with much interest our President's address, and as requested add some comments: Some such scale of intensities as Mr. McAdie proposes will, I think, eventually be adopted; but instrumental means of determining accelerations at a very large number of points in the megaseismic district must be available first; and I fear that will not be realized for many, many years. The Rossi-Forel and the Mercalli scales (although very imperfect), dependent as they are on observations which almost anyone can make, supply a practical means of describing roughly the distribution of intensities around the epicenter and the maximum intensity there.

I think the Society should publish accounts of all earthquakes in the United States, unless this is done by the Weather Bureau; in that case the most important work of our BULLETIN should be to publish special studies of particular earthquakes (such as have appeared), and articles on the general science of seismology. The publication of reports from all seismological observatories, and records of all earthquakes obtainable, is a very comprehensive work; it would cost us at least $10,000 a year. The International Seismological Association has been publishing this material, and will, I hope, continue to do so. The annual reports appear several years after the occurrence of the earthquakes listed; but there seem great difficulties in collecting the data, and this I am told produces a greater delay than the labor of preparing for publication.

I agree with our President that we do not need a large number of first-class seismological observatories; but there are still large regions in the West where good instruments, well cared for, would yield valuable information; and there certainly should be several in Alaska. It would be of great advantage if a large number of simple instruments could be spread about special districts to study their seismic activity.

By Stephen Taber

President McAdie in his address before the Society on August 4, 1915, offered tentatively a new intensity scale. This suggested scale resembles the absolute scales of Omori and of Cancani in that the intensity is measured in terms of the maximum acceleration stated in millimeters per second per second. The three scales differ from one another in the number of degrees (7 in the Omori scale, 12 in the Cancani scale, and 10 in McAdie's scale) and in the location of the boundaries between the different degrees.

Many other scales[1] have been proposed from time to time by different investigators, but only two have come into general use—the Rossi-Forel scale and the Mercalli scale. These two scales are very similar. Both have ten degrees of intensity defined by the effects of earthquake shock upon men, structures, movable objects, etc. They differ chiefly in the range of intensity allotted to each degree; so that the Rossi-Forel scale is somewhat better adapted to the gradation of slight shocks, while the Mercalli scale is more suitable in grading the intensity of strong shocks. Both Holden and Omori have estimated the equivalents of the degrees of intensity in the Rossi-Forel scale in terms of acceleration, but their determinations differ considerably. The degrees of McAdie's proposed scale seem to be more nearly equivalent to the Mercalli scale than to the Rossi-Forel scale.

The term *intensity* as applied to earthquakes has been used with somewhat different meaning by different writers; and in many writings, whether purposely or otherwise, the meaning has been left indefinite. A scale of intensity expressed in terms of acceleration has the advantages and also the disadvantages of being absolutely definite and precise in its meaning.

If acceleration be used as a measure of intensity, we must determine the amplitude and period of vibration at various points before we can compare the intensities at those points; as is necessary, for example, in drawing the isoseismals of an earthquake. It is possible to determine these quantities with considerable accuracy by using suitable instruments. The instruments used for this purpose, however, are costly, and those that are adapted to record slight shocks or distant earthquakes are useless for the purpose of recording the stronger shocks in the vicinity of their origins. For this reason it is seldom possible to determine the acceleration with any degree of accuracy at points near the origin of the disturbance. It is true that the destructiveness of an earthquake varies with the acceleration; it is for this reason that the effects produced by the shock have been used by most investigators in estimating and comparing the intensities at different localities. But there are other factors than acceleration that may control or partly control the amount of destruction wrought by earthquakes.

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[1] The various scales were collected and published by Dr. Charles Davison, *Philosophical Magazine*, **50**, 1900.

In general, the longer the duration of an earthquake the greater will be its destructive effects. In his paper on "The Earthquake in the Imperial Valley, California, June 22, 1915," Mr. Beal states: "The disturbance consisted of a fore-shock at about 7:40 p.m.; a heavy shock, which cracked and destroyed buildings and overturned chimneys, at about 8:00 p.m.; and another heavy shock nearly an hour later, which completed the destruction of the buildings already affected."[2] Elsewhere he says that "the intensities of the two shocks were practically the same."[3] The destructive effects would have been much less if the second strong shock had not occurred, and, if the interval between these two shocks had been an infinitesimal fraction of a second instead of an hour, the destructive effects would have been greater rather than less. On the other hand, there probably would have been no difference in the maximum acceleration whether the disturbance consisted of a single shock or of two shocks separated by an interval of time, however large or small.

Although the after-shocks of great earthquakes usually have a very much smaller acceleration than the main shock, the stronger ones frequently overthrow shattered walls and in similar ways add to the total destruction. This destruction, however, would be just as great or even greater if the interval between the principal shock and the after-shock were reduced to a small fraction of a second or even to zero; and yet there would be no difference in the maximum acceleration recorded during the disturbance.

Earthquake shocks vary considerably in their duration, and the effects produced are in part controlled by the duration of the disturbance.

Another factor of the utmost importance in the destruction of brick and stone buildings standing on unconsolidated alluvial deposits in the megaseismic areas of great earthquakes is the effect produced by the so-called visible waves or surface undulations. These waves have been observed during almost all of the very destructive earthquakes, but as yet little is definitely known concerning them. The great destructive power of these waves is due, not to acceleration, but to their large amplitude of vibration and comparatively short wave length. Their speed of propagation is relatively slow and they probably die out rapidly, for they are not noticed at a distance from the origin. They seem to be limited to unconsolidated deposits more or less saturated with water. Cracks have been observed to open and close in the ground during the passage of these visible waves, and soft alluvial ground is often permanently distorted. During the California earthquake of 1906, tidal mud near the head of Tomales Bay was thrown into wave-like ridges one to three feet in height, the interval between the crests being approximately 30 to 60 feet.[4] Similar but flatter wave-like ridges were produced on areas of made ground in San Francisco.

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[2] *Bulletin Seismological Society of America*, 5, 130, 1915.

[3] Ibid., 140.

When brick and stone walls are subjected to surface undulations of the kind just described the destruction is necessarily great. Walls that are approximately at right angles to the direction of wave transmission are tilted back and forth until they are overturned, and the fallen stones tend to retain the same relative positions that they formerly occupied. Walls standing parallel to the direction of wave transmission are destroyed by shearing stresses, and fall in irregular piles. After the California earthquake of 1906 the damaged walls and arches at Stanford University furnished mute evidence of the passage of surface undulations.[5]

Occasionally it is possible to make rough estimates of the maximum acceleration from the data furnished by displaced objects. For example, during the Assam earthquake boulders were projected into the air, thus indicating that the maximum vertical acceleration was greater than that due to gravity.[6] But the use of an intensity scale measured in terms of acceleration, it seems to the writer, is impractical so long as in making our estimates, in megaseismic regions at least, we must depend upon the effects of the shock upon structures and movable objects.

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[4] Gilbert, G. K., "The Earthquake as a Natural Phenomenon," in The San Francisco Earthquake and Fire of April 18, 1906, *U. S. Geological Survey Bulletin,* 324, p. 13, 1907.

[5] Taber, S., "Some Local Effects of the San Francisco Earthquake," *Journal of Geology,* **14**, 313, 1906.

[6] Oldham, R. D., "Report on the great Earthquake of 12th June, 1897." *Memoirs Geological Survey of India,* **29**, 354-358.

The Rossi-Forel scale furnishes a ready means of measuring the effects of earthquake shock; also, it has long been in general use in this country, and since the founding of the Seismological Society of America it has been published in the back of each issue of the BULLETIN. In this scale the degrees of intensity from I to III are determined from the effects of the shock upon persons and on instruments designed for the purpose of recording earth movements. It is due to their acceleration that the slight vibrations of small amplitude are noticed by people; and when they pass unfelt, it is because the acceleration is too small to be perceptible to the senses. Therefore the first three degrees of the Rossi-Forel scale are really a measure of the relative acceleration.

The degrees of intensity from IV to X in the Rossi-Forel scale are estimated partly or entirely from the effects of the shock on buildings and similar structures; but the styles of architecture and kinds of building material vary greatly in different countries and even in different sections of the same country. The enormous loss of life during the earthquakes of Messina and Avezzano, as compared with the Charleston and San Francisco earthquakes, was not due to greater intensity, but is chiefly to be explained by the character of the buildings. In Italy the buildings are entirely of stone and brick, frequently put together with poor mortar; while in the United States the majority of buildings are constructed of wood.

This variation in the type of structures makes the comparison of maximum intensities difficult when the disturbances are located in different regions. In the study of a single earthquake, however, we need to know chiefly whether the intensity at a given place was greater or less than at another place—we are concerned with relative rather than with absolute intensities.

Accurate comparison of the intensities at different points can be made only after eliminating as far as possible all errors due to the personal equation. The question cards adopted by the U. S. Weather Bureau for use in collecting earthquake data are calculated to increase rather than decrease these errors, in that they call upon inexperienced observers to make estimates of intensity. Few people will even approximately estimate the intensity; and for the sake of uniformity, it is preferable that all estimates be made by the person compiling the data. When it is impossible for the investigator to visit the various points in person, his estimates are likely to be more accurate if based upon the answers to a series of graded questions. And, in passing, the writer would suggest that it is not possible to frame these questions too simply.

The objections to the Rossi-Forel scale are obvious; and if its use is to be continued, it should be revised to suit conditions in this country today. Dr. Branner and others have already called attention to the absurdity of defining intensity III of the scale by stating that it is "strong enough for the direction and duration to be appreciable," when experienced observers are unable to distinguish the direction of motion from the effects of the shock upon their senses. Moreover, in this country, church bells are not common today, swinging house bells are rapidly disappearing, and a pendulum clock is the exception rather than the rule.

While the comparison of the intensities of earthquakes is of great value, "the energy set free," as Dr. Reid has well said, "is the *fundamental quantity* involved in an earthquake, and it is of the greatest importance to estimate its amount and to compare the amounts liberated by different earthquakes." [7] The maximum intensity of an earthquake gives no indication of the amount of energy liberated. For instance, the Charleston earthquake was in no sense remarkable for its intensity —it has been surpassed in destructive effects by many earthquakes— but very few earthquakes of which we have any knowledge have surpassed it in the amount of energy liberated.

While there are many difficulties involved in the estimation of the relative energies liberated by earthquakes, if we adopt the method suggested by Reid,[8] and use some isoseismal below IV in the Rossi-Forel scale, we will at least eliminate any errors that might be introduced because of the difference in the types of buildings found in different regions.

Many different factors enter into the cause and the effects of an earthquake. In comparing earthquakes all of these factors should be taken into consideration. It is not sufficient to estimate the maximum intensity of a disturbance according to one scale or another and then pigeon-hole the shock on the basis of this classification. In studying and comparing earthquakes, the duration, the maximum acceleration and amplitude, the relative destructive power, the area enclosed by different isoseismals, and the total energy liberated, are among the more important factors which should be determined whenever possible. Unfortunately it is rarely possible to determine all of these.

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[7] Reid, H. F., "The Energy of Earthquakes," C. R. De L'Association Internationale De Sismologie, Manchester, 1911.

[8] Ibid., p. 3.

University of South Carolina,
November 12, 1915.

By Francis A. Tondorf, S. J.

In view of the chaotic condition prevalent in Trans-Atlantic countries, the suggestions of our President, as voiced in his inaugural address before the Seismological Society of America at Stanford University on August 4, 1915, must generally be accepted as highly pertinent. As far back as 1904 Dr. Sieberg anticipated the complaint against the Rossi-Forel scale when he wrote: "Diese (Rossi-Forel) Skala dürfte jedoch nur mehr Kurze Lebensdauer besitzen," and yet eleven long years have proffered no universally accepted substitute. Again in 1903 the second International Seismological Conference solicited suggestions regarding a workable intensity scale for microseismic disturbances, with the result that nothing definite has been realized to date. It would seem therefore, now that the statutes of the International Seismological Association are about to expire by limitation, that the iron, red of heat, awaits the blow. The scale suggested would appear eminently calculated to meet every emergency, but at all events, should not be adopted without the general approval of our European confreres. A hearty endorsement is given the opinion that the further establishment of seismological observatories in our country is superfluous. Why not—and this was urged upon Congress some three years ago by the authorities of the United States Weather Bureau—have the government, apparently anxious to foster this line of scientific research, subsidize the existing chain? The number of these observatories is well nigh twenty-five, with the best of equipment and choicest location. Nor need they be isolated units. Most of them are already in close touch with astronomical institutions and could be readily manned for meteorological investigations.

Georgetown University Seismological Observatory,
Washington, D. C.

COMMENT BY PRESIDENT MCADIE ON THE REMARKS MADE BY VARIOUS MEMBERS

In a Society constituted as ours is, it is not practicable for the members to meet and have the benefit of a personal interchange of views and opinions. Nor have we any of the discussion from the floor practiced in most societies. We are scattered over a large area, and for the most part our occupations and emoluments do not permit of prolonged absence from home duties. It is therefore most desirable that we should find a forum in our BULLETIN; and that in its pages there should be as full and free discussion as is possible of such problems as may arise. It was with a view of bringing out a general expression of opinion that the writer in his address at the August meeting made certain definite propositions and invited comment thereon. Briefly these propositions were:

1. Shall we give up the Rossi-Forel scale and adopt a new intensity scale, in recording earthquakes? A new scale built upon the Omori and Cancani acceleration scales was tentatively proposed; and in this, maximum acceleration in ten intensities was to be used.[1]
2. Shall we adopt a uniform time scale, preferably Greenwich mean civil?
3. Shall we use a suitable symbol for time at the origin?
4. Shall we attempt the prompt publication of all determined epicenters?
5. Shall we urge the establishment of more observatories in the United States, or have we now enough?
6. Shall we request the assistance of the Department of State in bringing about international cooperation in collecting, reducing and publishing records from Central and South America, Canada (Pan-America?), Asia, Australia, and also Europe?
7. Shall we suggest that a joint committee from Coast Survey, Geological Survey and Weather Bureau be asked to undertake the preparation of world-wide reports?
8. Shall our seismological observatories have their scope of work extended so as to become practically pan-observatories, so that there may be quick correlation of seismic, magnetic, and atmospheric phenomena?
9. Shall we take upon ourselves the task of restoring international comity and re-establish the bond of union among seismologists of all nations, which the war has sadly broken?

The writer is exceedingly gratified by the number and character of the answers; and wishes to express his thanks to those who have thus discussed the questions raised.

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[1] *Bulletin Seismological Society of America,* **5**, 123, September 1915.

Professor Taber discusses at some length the problem of an intensity scale, and shows very properly that other factors than acceleration may enter into what may be called the "destructive" effect of an earthquake. Undoubtedly, repetition of shocks may cause damage which would be out of proportion to the value of the acceleration; and if the entire disturbance were to be rated according to the maximum acceleration during any partial interval of time, the classification would be misleading and the method faulty. But there would certainly be given, in any complete record of a destructive earthquake, the information which would make plain the contributory factors. It is also true, as Dr. Taber points out, that "the styles of architecture and kinds of building material vary greatly in different countries"; and so the destructive effects may vary for the same degree of acceleration. But if we can show positively that such is the case, then a decided step forward has been made; and we are in a position to advise intelligently regarding construction, material, etc. I agree with his view that the cards used at present in collecting information are calculated to multiply certain errors.

Professor Reid, who perhaps of all our members has had the widest experience in determining earthquake intensities, thinks that some such scale as proposed will ultimately be adopted; but emphasizes the need of many instruments in the megaseismic district. What is the minimum number needed in a given area? It would be an interesting experiment to install a given number of instruments in a given area, and determine how many were really needed. Dr. Reid is hopeful that the International Association will continue publishing comprehensive reports; but I confess I can not see from where the funds for such work will be forthcoming; for undoubtedly all budgets for scientific work of this kind will be materially reduced at the close of the war.

Professor Durand's discussion seems to me to be right to the point. I do not quite agree with the view that all records must be imperfect, from the nature of the instrument. It is true no record is free from error; but in most modern instruments care is taken to check up records, and due allowance is made for all determinable sources of error. The suggestion of the carbon contact and change of electrical resistance with change of pressure, may perhaps lead to a new form of seismograph. If we are not mistaken, however, some such principle has been tried, possibly by Father Odenbach at Cleveland. Undoubtedly there is room for invention of new seismographs along such lines, although certain practical difficulties can be foreseen; and constant calibration will be needed. Professor Durand makes the pertinent suggestion that gravitational units be employed; but do we not generally express gravity in terms of acceleration?

Professor Marvin is in favor of an acceleration scale of intensities, but takes, as it seems to us, an unnecessarily gloomy outlook regarding instruments. He has perhaps in mind the difficulties experienced in connection with the strong-motion seismograph,[2] which, however, was modified by others, and may yet give a record of the desired character. We certainly hope so; but we can not believe that the lions in the way of the instrument maker are so very great, now that ample means are available and there is no question as to the legality of expenditure of public funds for seismographs. In former years money spent for seismographs, as we understand, lacked the sanction of legal authority.

Father Tondorf expresses the view that the Rossi-Forel scale has now outlived its usefulness, a view in which most of us coincide. He heartily indorses the view that there is no present need for further observatories in the United States, and proposes that some recognition of existing observatories be made. There are now in operation about twenty-five,—quite a large number; and it does not appear that much is to be gained by increasing the number. Father Tondorf, by the way, has begun at Georgetown University the publication of a bulletin giving general seismographic news and data as gathered from all sources.

This may be the beginning of an important news service. The astronomers have their "Nachrichten" and "Monthly Notices R. A. S." Why not something of a like character for the seismologist?

Finally, it will interest the members of the Society to know that Dr. Klotz has nearly ready for the printer a Handbook for the working seismologist. It goes without saying that such a book must needs be helpful in bringing about mutual cooperation and uniformity of notation.

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[2] *Bulletin Seismological Society of America*, 3, 195.

THE PLEASANT VALLEY, NEVADA, EARTHQUAKE OF OCTOBER 2, 1915

By J. Claude Jones

A severe earthquake was felt throughout Nevada and the adjoining parts of the neighboring states shortly before eleven o'clock on the night of Saturday, October 2, 1915. The area in which the shock was perceptible extended from Baker, Oregon, to San Diego, California, about eight hundred miles north and south; and from the Pacific coast to beyond Salt Lake City, or about six hundred and fifty miles east and west. The cause of the earthquake was a movement along a fault on the eastern border of Pleasant Valley, Nevada, a typical elongate, north-south valley of the Great Basin, twenty-five miles long, whose northern end is about forty miles south of Winnemucca. The fault appeared at the surface as a fresh vertical scarp from five to fifteen feet in height, running for over twenty-two miles along the junction of the bajada or alluvial apron and the base of the Sonoma Range.

While the earthquake was felt over as large an area as that of the California earthquake of 1906 and was probably as severe, the damage that resulted was comparatively small owing to the small number of structures in the sparsely populated area in the vicinity of the center of disturbance. Had it occurred in a more densely settled district it probably would have been numbered among the more destructive earthquakes of history. The earthquake is of especial interest to geologists because the Sonoma Range is a typical basin range, and it is evident that movement has not entirely ceased along the faults that bound the range on one or both sides.

During the week following the earthquake the writer, in company with Professor H. P. Boardman of the University of Nevada, spent two days in Pleasant Valley, and traced the fault rift throughout its length. The area is included in that mapped by the geologists of the Fortieth Parallel survey,[1] and the accompanying topographic map (Fig. 7) has been traced from the geologic map of the Nevada Basin.

Ordinarily the gathering of the necessary information over such a wide and sparsely settled area would have been a long and difficult task. Through the generous assistance of many friends, sufficient data have been collected to outline the broader features of the earthquake; and the sincere appreciation of the writer for the prompt and kindly aid extended is here recorded. Among those to whom especial acknowledgment is due are Mr. H. F. Alciatore, Section Director of the U. S. Weather Bureau at Reno, who gave free access to the reports of the cooperative observers in his section; Mr. E. F. Davis of the Seismographic Station of the University of California, who forwarded an account of the records of the earthquake secured at Berkeley and the Lick Observatory, and generously turned over the information he had collected elsewhere; Mr. L. G. Campbell of Winnemucca, who made it possible to promptly visit Pleasant Valley; Mr. Carl Stoddard, field geologist of the Southern Pacific Railroad, who furnished photographs and information concerning the secondary cracks developed near Lovelock, Nevada; and Mr. W. G. Greiner of Reno, who gave information as to the effect of the earthquake on hot springs near Battle Mountain, Nevada.

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[1] King, Clarence: Geol. Exploration Fortieth Parallel; Atlas, map 5. 1876.

Pleasant Valley is located in the north central part of Nevada, in the southeast corner of Humboldt county, some forty miles south and a little east of Winnemucca (Fig. 1). It is a long, narrow, intermontane valley, lying between two of the Basin ranges known as the Sonoma and East (~~Humboldt~~) ranges. It contains five or six ranches, but aside from the small mining town of Kennedy located in the East (~~Humboldt~~) range opposite the center of the valley, there are no other permanent settlements. The nearest towns of any size are Winnemucca and Golconda to the north, Battle Mountain to the northeast, and Lovelock to the west, all approximately fifty miles from the center of the fault rift. Reno, the largest city in Nevada, is one hundred and twenty-five miles away, to the southwest.

The main shock of the earthquake was preceded by two foreshocks, that were felt throughout the northern half of Nevada. The first of these occurred at 3:40 p.m., Pacific Standard Time, and was barely perceptible at Reno. At Kennedy a loud report was heard that sounded similar to an underground blast of dynamite, and the ground gave a sudden lurch to the north, and continued to vibrate for five seconds. While no damage was done, the shock was sufficient to thoroughly alarm the inhabitants of the town. In the surrounding cities it was felt generally, and its intensity varied from I to III, R.-F. scale, depending on the distance from the center of disturbance.

The second foreshock occurred at 5:49 p.m., and was felt to a considerable distance further than the first. At Kennedy faint rumbles

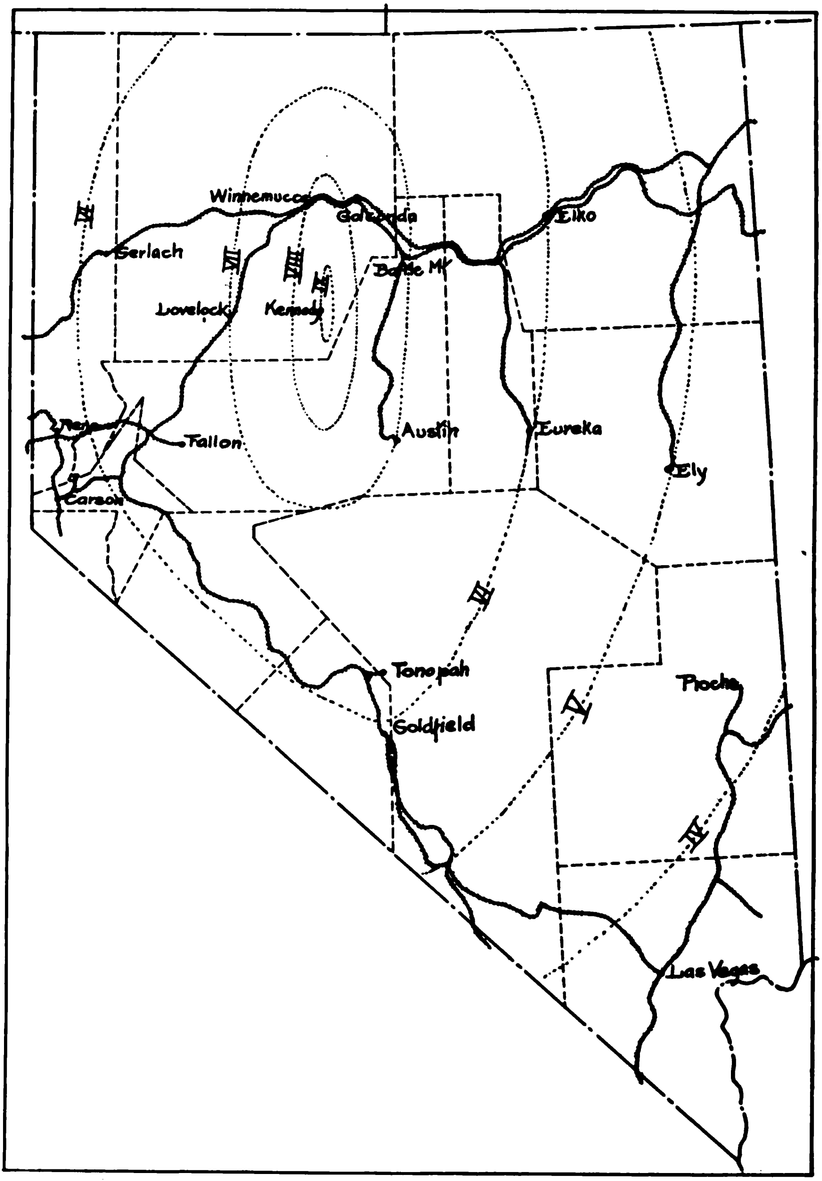

Fig. 1. Map of Nevada showing isoseismals and origin of earthquake of October 2, 1915.

and tremors had been heard and felt from the time of the first shock. Suddenly a roar was heard, and the earth's surface was so greatly agitated that it is stated that people standing had difficulty in keeping their feet. At Reno several clocks were stopped, and the shock was generally noticed, especially by those in the upper stories of the buildings. The intensity in the towns near the origin was VI (R.-F. scale), V at Reno, and the shock was felt as far west as Grass Valley, California, two hundred miles away.

At the seismographic station of the University of California at Berkeley the first foreshock began about 3:41 p.m., and continued for about nineteen minutes. The maximum horizontal movement of the ground was equal to 61 microns, and the period of vibration during the maximum from six to eight seconds. At the Lick Observatory similar records were obtained on the horizontal components, while the vertical component gave a barely perceptible record.

The second foreshock began about 5:49 p.m., and lasted nearly an hour. The maximum amplitude was 460 microns in the east-west component, and the period about eleven seconds. The vertical component was not running at the time, but at the Lick Observatory the maximum amplitude of the vertical component was 388 microns, with a period of three and a half seconds.

The principal shock occurred at 10:54 p.m. The earthquake at Kennedy has been graphically described by Mr. L. StD. Roylance in the *Silver State* (Winnemucca) of October 5, 1915, and his account gives a very vivid picture.

"From this disturbance (second foreshock) on, it was an incessant continued trembling, the earth never appearing quiet. About nine o'clock we retired for the night, and as nearly as I can describe the situation, one could shut his .eyes and imagine he was occupying a berth in a moving Pullman car, accompanied with creakings and rattling of windows, to be abruptly awakened by outbreaks at intervals of twenty to thirty minutes, lasting from five to ten seconds. At 10:54 things had quieted, or perhaps we were unconscious in sleep, when without the slightest warning a great roar and rumbling was heard and we were thrown violently out of bed and buffeted in all directions continuously for not less than fifteen minutes.[2] During this disturbance the earth would appear to tire itself, and would hesitate for an instant, as if it were changing hands and fumbling to get a good grip, and would then shake violently with the other hand until tired; then it would change hands again and repeat the operation.

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[2] The time reported by Mr. Roylance seems unusually long, as it represents the time that actually elapsed before the vibrations of the earth had quieted so that he returned to the house. The strong aftershocks that followed closely after the main shock made it seem as if the earthquake had continued for the length of time mentioned.

"The sensation of being shaken and buffeted about the room almost knocks the reason from one's head, and he acts mechanically in an endeavor to get outside. When outside, an opposite impulse seizes you, and your one thought is to get inside again. During this state of mind one appears to lose all reason, and flounders about like a ship without a rudder, and with only one desire—for the commotion to stop."

In the early newspaper reports the entire town of Kennedy was stated to have been destroyed. Mr. S. L. Berry, superintendent of the mill at Kennedy, stated that the only damage done was the utter destruction of a couple of adobe houses and the cracking of the concrete foundations in the mill. A considerable portion of the mine tunnels were caved and one of the solution tanks in the mill damaged, but the damage was repaired in a day.

At the Cooper and Uniack ranch (Fig. 7), at the southern end of Pleasant Valley and located two miles west from the fault rift, Mr. Cooper stated that a row of poplars growing along a ditch running south near the house were whipped back and forth by the earthquake until their tops nearly touched the ground on either side. An adobe house was completely shaken down, and a small shed thrown out of plumb. The main house, newly built of concrete, was on alluvial ground sloping gently to the east. Owing to the unconsolidated condition of the soil it slipped a few inches downhill to the east, opening several cracks running north and south and under the house. The foundation of the house had been cast separately from the walls, and as the eastern two-thirds of the foundation broke and slipped several inches down the slope the house moved with it. The drag of the rear wall on the part of the foundation that remained in place opened up a gap of six inches between the wall and partitions through the rear of the house. Otherwise the house was but slightly damaged.

At the Pierce ranch, ten miles further north and within two hundred yards of the fault rift, an adobe barn was partially destroyed. At Siard's ranch, located in the center of the valley and about two miles west of the fault rift, the poultry-house and hog-pen and part of the dwelling were built of masonry. The hog-pen and poultry-house were completely destroyed and the roof of the poultry-house thrown six feet to the northwest. In the photograph (Fig. 2), taken looking to the south at the ruins of the poultry-house, the men are standing in

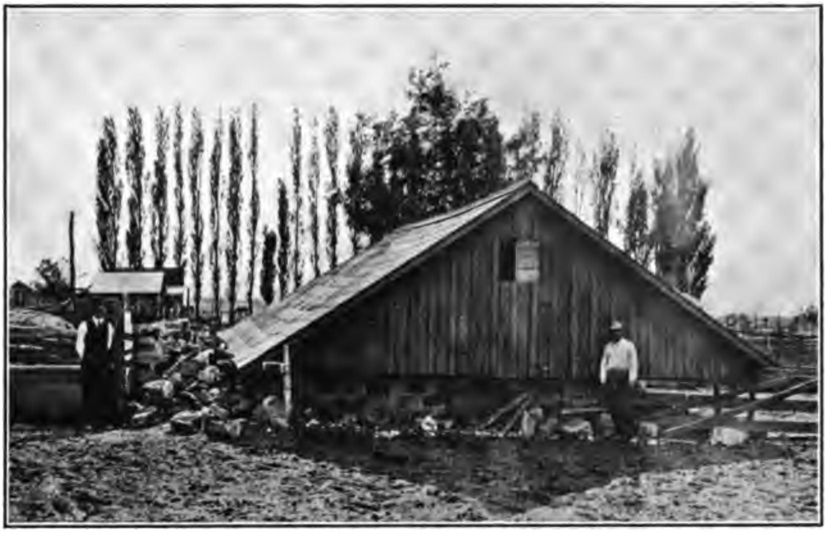

Fig. 2. Effect of earthquake on poultry-house at Siard ranch, Pleasant Valley, Nevada. H. P. Boardman, photo.

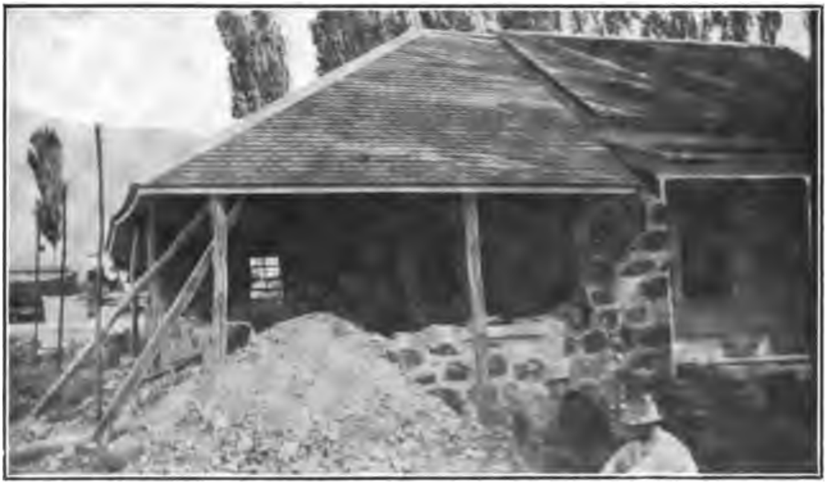

Fig. 3. Effect of earthquake on dwelling house at Siard ranch.

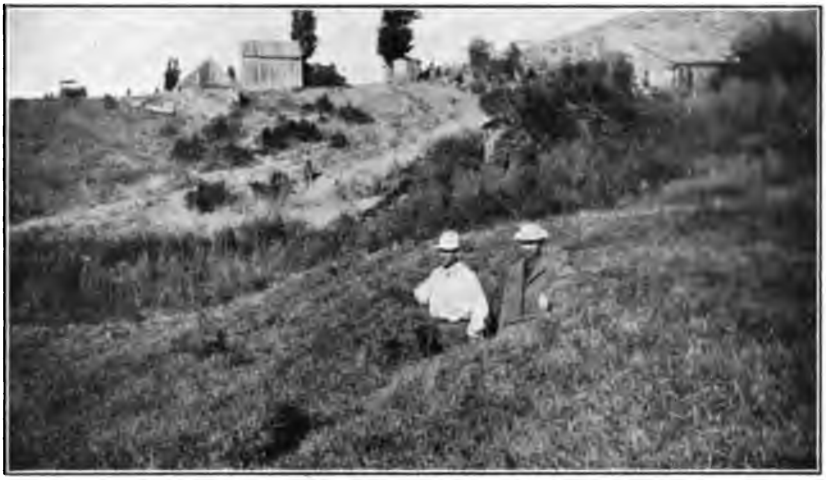

Fig. 4. Looking north along earthquake rift at Shell ranch, near northern end of Pleasant Valley.

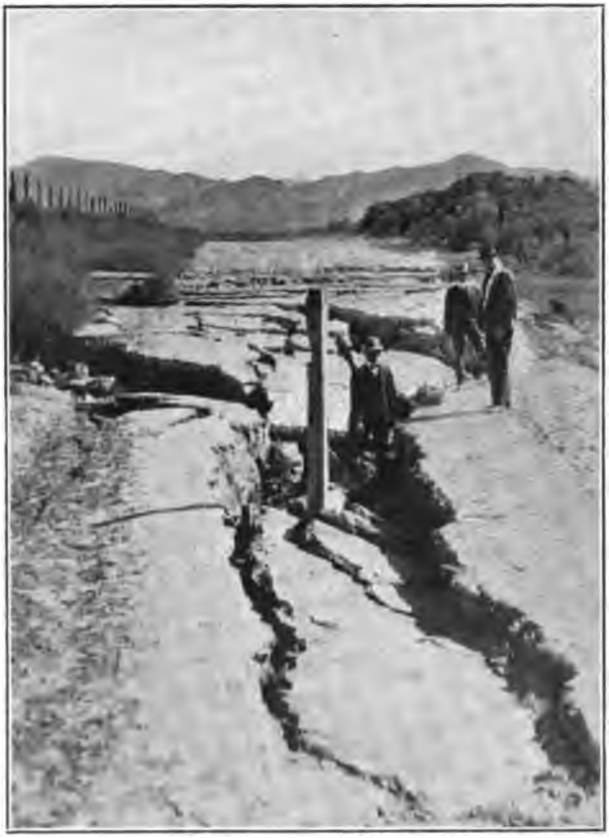

Fig. 5. Cracks developed by earthquake in alluvial soil near Lovelock, Nevada. Carl Stoddard, photo.

line with the foundation, and the amount and direction the roof was thrown is plainly evident. The house (Fig. 3) was partly of frame, and had a newly built addition of masonry to the north. At the time of the writer's visit the roof had been shored up into place, but it was stated that it had been thrown in the same manner as the roof of the poultry-house. The frame portion of the house was racked, and the plaster cracked.

The smaller amount of damage done in the immediate vicinity of the fault rift is strikingly brought out in the photograph (Fig. 4) looking north at the Shell ranch at the northern end of the fault rift. The rift may be seen in the foreground, crossing the meadow and running up over the low ridge just back of the small cabin. Although the barn is constructed of the same masonry as at the Siard ranch it was undamaged. The only damage that was noticed was the breaking of the irrigating ditches where they crossed the rift, and the development of a four-foot vertical cliff in front of the gate to the corral. An underground cellar faced with an uncemented rock wall at the Pierce ranch, and located within a hundred feet of the rift, was similarly undamaged.

At Mud Spring, in the northern end of the valley, a frame house was moved twelve inches to the northwest from its foundation, but was only slightly damaged in any other way. Several rock-falls were noted in the Sonoma Range throughout the length of the valley.

Outside the area in the vicinity of the fault the earthquake was felt as a rapid series of swings, with little jerking or vertical motion, that continued for an unusually long time. Several observers who accurately timed the duration of the shock report that is was felt for a period of from forty to fifty-five seconds. The rapid rocking motion seemed most like that of a boat in the trough of a choppy sea, and produced a feeling of vertigo or nausea in several persons.

At Winnemucca the greater damage was confined to the northern side of the city, where the buildings are on low ground, near the Humboldt River. Several two- or three-story brick buildings had the coping and part of the upper walls thrown down; adobe buildings were generally damaged, and in one case the upper part of the north and south walls were thrown to the west; two plate-glass windows were broken in the store of E. Reinhart and Co.; and many chimneys about the city were demolished above the roofs of the buildings. Articles lying loose upon the shelves of the stores were thrown to the floor, and the greatest loss was suffered by the druggists from the breakage of glass.

At Golconda adobe buildings were cracked, merchandise was thrown to the floor, cracks appeared in the cement floor of the Western Pacific Depot and in the earth in the switching yard, and the approach of the bridge of the Southern Pacific Railroad sank five inches. Golconda is entirely located on the low ground adjoining the Humboldt River.

At Battle Mountain the water-tank of the Southern Pacific was thrown down, plaster was cracked, and chimneys damaged. Near Palisade rocks were thrown upon the tracks of the Western Pacific Railroad in the canyon of the Humboldt River. At Elko little damage was done other than the throwing of a few articles from the shelves of one of the stores; but at the ranch of Mr. Cook, about fourteen miles southeast, boggy ground surrounding a hillside spring slid into the valley and left a depression three hundred feet in diameter and twenty feet deep. The spring continued to flow in the depression with a greater volume than before.

At Lovelock several brick walls were cracked and damaged, a few chimneys broken at the roof line and rotated, and the water-tanks of the Southern Pacific Railroad were thrown down at Parran and Kodak, nearby. Near the flour mill of Mr. W. C. Pitt, about five miles north of Lovelock, the saturated alluvium along a slough of the Humboldt River settled unevenly and left cracks with vertical faces two and three feet high. The county road was damaged, as is shown in the photograph (Fig. 5).

At Fallon articles were thrown from the shelves, and piles of sacked grain and flour thrown down. Near Austin an adobe house was shaken down and a brick building damaged. At Gerlach, located at the southern end of the Black Rock Desert on the playa, cracks opened in the freight yards of the Western Pacific Railroad, the concrete floor of the depot was cracked, and water-pipes broken. Cracks are reported in the playa east of the West Humboldt Range near Unionville, and rock-falls occurred in the mountains.

The damage was confined to the area within fifty miles of the fault rift, with the exception of those localities such as Gerlach, that are situated on water-saturated alluvium. In plotting the isoseismal lines (Fig. 1) no great accuracy can be claimed, owing to the wide separation of the towns where the damage would be noticed. While the majority of the towns are located on the low, unstable, saturated alluvium of the playas and the valley of the Humboldt River, which would tend to increase the damage done, yet the fact that most of the buildings are frame structures and the chimneys predominantly of metal would tend to minimize the amount of destruction, and it is believed that the lines are essentially correct.

With but few exceptions the direction of movement as reported by the various observers in Nevada was radial from the source of disturbance. The direction in which loose objects were thrown was observed in too small a number of instances to allow of generalization; but in such cases as the observation was made, they seemed to be thrown in a direction away from the center of disturbance.

One of the most striking effects of the earthquake was the large increase in the flow of streams and springs throughout the northern part of Nevada. In Pleasant Valley all of the streams issuing from the Sonoma Range trebled or quadrupled their flow, until water stood on the playas, a circumstance that had not been known to happen at this time of year before. In the southern part of the valley along the edge of the stream channel many secondary cracks developed; and wherever these crossed the wash of a tributary, water flowed over the surface for several days following the earthquake. Mud craterlets were developed in many of the cracks that were otherwise dry, showing that muddy water had been forced through them at the time of the earthquake. The experience of Mr. W. L. Pierce, who was camped at Mud Spring at the northern end of the valley at the time of the earthquake, is quite suggestive. He states that with every lurch of the ground the spring, which ordinarily has but a feeble flow, spurted water into the air to a height of two or three feet. It is probable that muddy water was similarly forced out of the secondary cracks where they developed in soil saturated as is the ground in the stream channel at the southern end of the valley.

Similar craterlets developed to some extent in the secondary cracks five miles north of Lovelock.

A line of hot springs located along a fault near Golconda were diversely affected. Some went dry, while the flow of others was increased. A cold spring started to flow in the immediate vicinity. At the Wingfield ranch, thirty miles south of Battle Mountain, the flow of the hot springs largely increased, and a hay-field was flooded. The flowing springs became considerably hotter, and many springs not known to flow before, or which had apparently become extinct, began to flow. The increase in volume of one of the springs was sufficient to tear out the old peaty soil that had filled its basin, and spread the fragments over a considerable area.

The hot springs near Elko rose several inches, while the spring near Carson became dry and remained so, and drilling was necessary before the flow resumed. The increase in the flow of the streams and the breaking out of new springs was such a common occurrence in the area within fifty miles of the origin of the earthquake that the office of the State Engineer received over fifty applications for the new water rights. The Feather River at Portola, California, is reported to have risen ten inches and maintained the flow for several days.

In explanation it may be said that in Nevada the greater portion of the flow at this time of the year in the stream channels is through the sands and gravels, and very little appears at the surface except at times of unusual precipitation. In the few cases where the increased flow was investigated it was found that the increase was rising from secondary cracks developed in the sands and gravels of the stream beds. It is evident that these cracks offered an easier path for the underflow than through the sediments, tending to drain the water stored in them above the fissures, and that in time the streams will return to their normal *regimen.*

A small Ewing Duplex Pendulum is installed in the basement of the Mackay School of Mines at Reno, and a photographic reproduction of the record is shown as Fig. 6. The building stands on the alluvial fill of the valley, and it is not known how much the four hundred feet of alluvium affects the intensity of the earthquake vibrations. The entire movement is not recorded, as the pendulum struck the guard-ring several times during the passage of the earthquake. The maximum movement of the pen actually recorded is eleven centimeters, and as nearly as can be determined this represents a tilt of slightly over one millimeter.

The rather even character of the vibrations is shown by the simplicity of the lines and the relative scarcity of abrupt changes in direction. The pen was at the center of the plate at the beginning of the earthquake, and the small snarl of lines there is the start of the record. The first vibrations were chiefly in a north-south direction, and as the earthquake progressed the heavier vibrations became east and west. This was also shown by the east-west vibrations of the chandeliers at the close of the earthquake. The larger snarl at the right of the figure was produced by the closing vibrations. There was enough vertical movement at times to cause the pen to jump and produce dotted lines. From the close spacing of the dots, however, the vertical movements were not heavy or sudden enough to throw the pen more than a short distance above the plate.

Mr. Davis states that at the Berkeley Station the first movement of the ground was to the south and west, or away from the origin of the earthquake. The periods of vibration of the first preliminary tremors were unusually long, being as high as ten or fifteen seconds. During the main phase of the earthquake the intensity was high enough to start the Marvin strong-motion seismograph, and a partial record of the main phase was obtained on that instrument. The Bosch-Omori horizontal seismographs were dismantled, and after a few long strokes the pens left the paper.

Complete records were obtained with the Omori tromometer, and the measurements as determined by Mr. Davis follow:

iP	10^h	54^m	31^s	p.m. (Pacific Standard Time)
iS	10	55	34	
iL	10	55	51	
M_E	10	56	08	
M_N	10	57	00	
C	10	58	00	
F	1	51		

The maximum amplitude on the east-west component was 870 microns, and the period one and a half seconds. In the north-south component the maximum amplitude was 515 microns, and the period two seconds. The vertical component was not running at the time, but from the trace on the paper it seems certain that the vertical movement had an amplitude of at least 725 microns.

At the Lick Observatory the north-south component was dismantled at the beginning of the main phase, but complete records were obtained on the east-west and vertical components. The maximum amplitudes recorded were 760 microns, with a period of six seconds, on the east-west component; and 520 microns, with a period of two and a half seconds, on the vertical component.

Mr. Davis remarks: "The time of duration of the earthquake at Berkeley is notable. At first it was thought that a distant earthquake had occurred at about the same time as this strong near shock, and that the record was a combination of their seismograms. It seems more probable that the long duration of motion was due to the continuous arrival of energy from the group of strong aftershocks which followed the main earthquake. This seems practically the only explanation, since no other strong earthquake is known to have occurred elsewhere at this time." Aftershocks were recorded at Wonder and Fallon at 11:05, 11:18, 11:33, and 11:49, though only one of them was strong enough to leave a perceptible record on the Ewing instrument at the University of Nevada.

Mr. Davis states that excellent records of the earthquake were obtained at practically every seismographic station in the country. The intensity of the main phase of the earthquake was sufficient to dismantle one or more components at the Universities of Washington and Utah, and at Harvard and Yale Universities. At the University of Utah the preliminary tremors showed the same long period as at Berkeley. Dr. F. Napier Denison reported a maximum amplitude of 1000 microns registered by the Wiechert Vertical Seismograph at Victoria, B. C. Records furnished Mr. Davis by Rev. A. W. Forstall of the Sacred Heart College of Denver showed maximum amplitudes of 537 microns north-south, and 687 microns east-west.

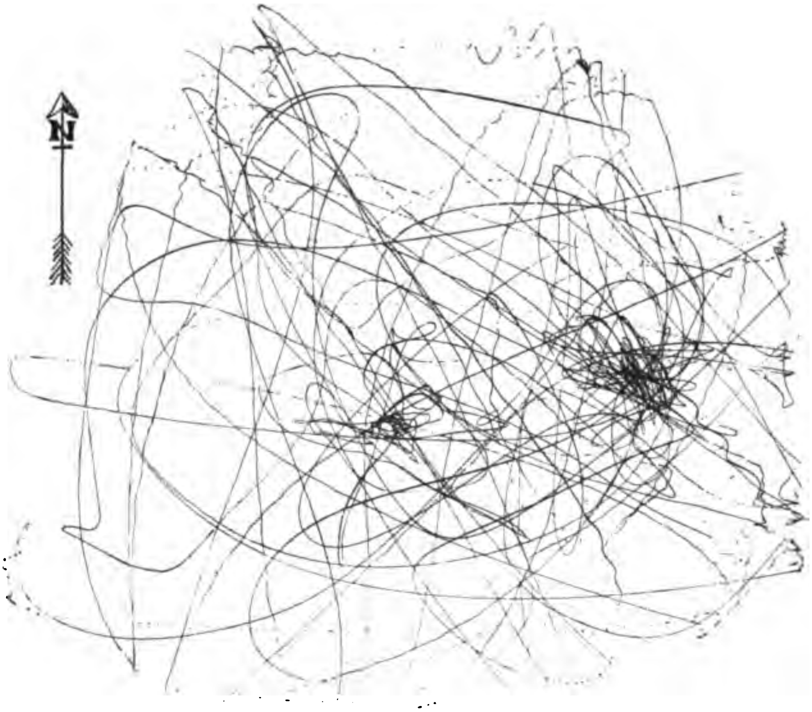

Fig. 6. Record made by Ewing Duplex Pendulum at University of Nevada, Reno, Nev., October 2, 1915.

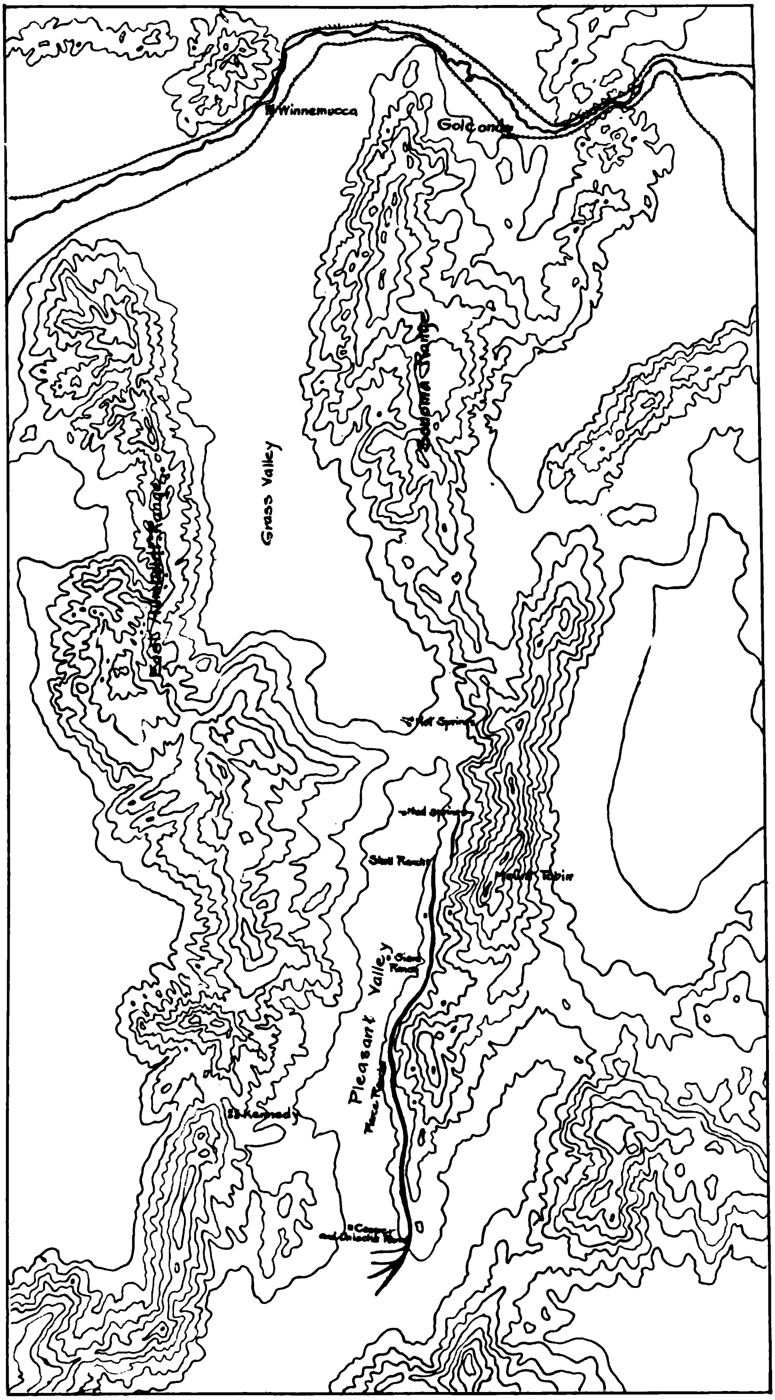

Fig. 7. Sketch map of area in vicinity of origin of earthquake. Topography from Fortieth Parallel Survey. Scale 1 in. = 8⅓ miles.

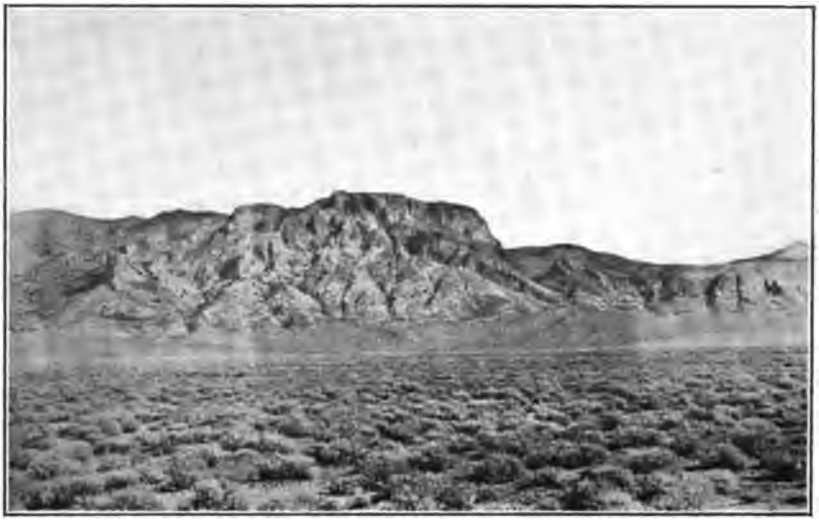

Fig. 8. Earthquake rift along base of Sonoma Range, about four miles north of Pierce ranch.

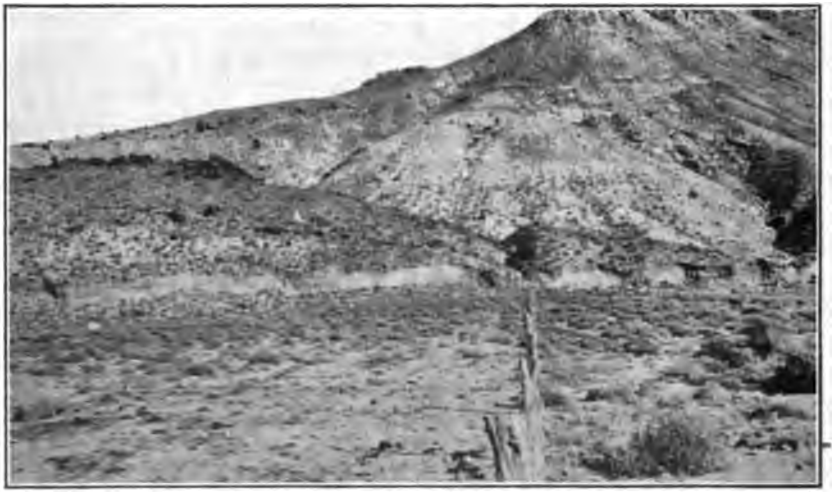

Fig. 9. Earthquake rift at Pierce ranch; the continuous line of the fence across the rift shows the purely vertical movement of the fault.

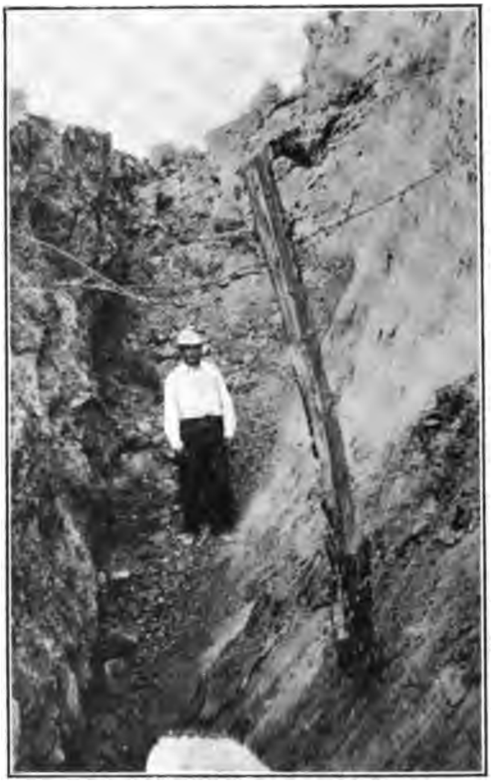

Fig. 10. Looking north along earthquake rift at Pierce ranch, showing striated rock surface at bottom of pit.

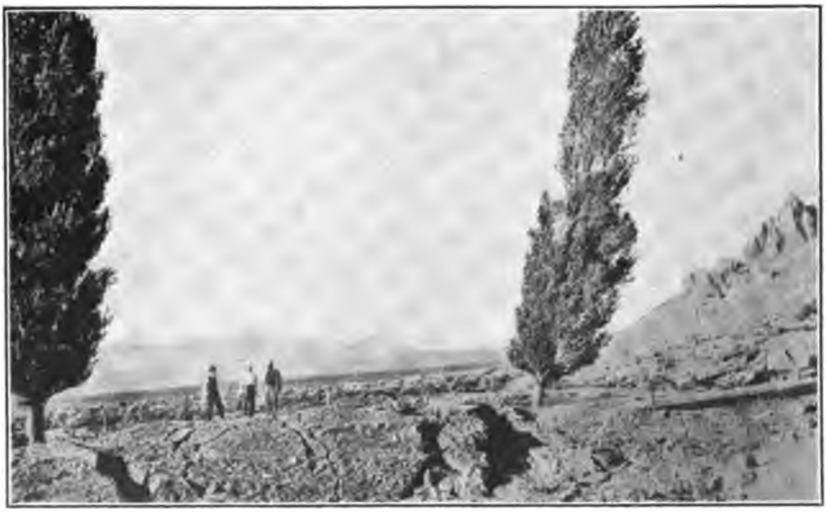

Fig. 11. Looking north just west of rift at Pierce ranch, showing development of secondary cracks and tilting of tree by earthquake.
H. P. Boardman, photo.

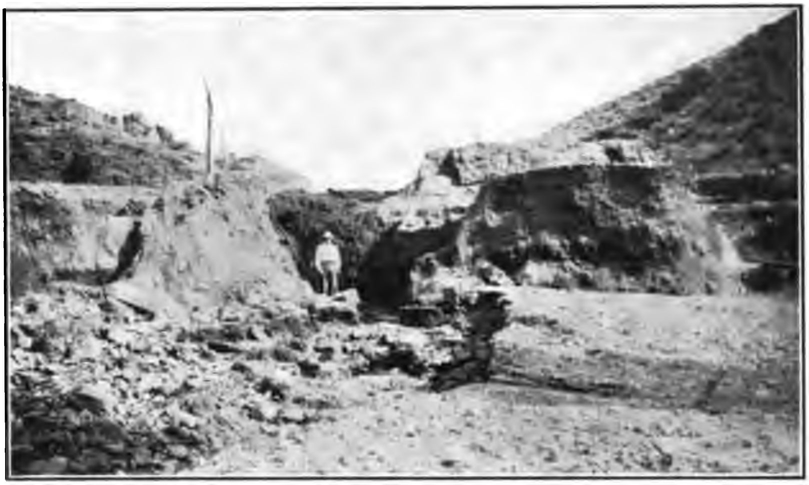

Fig. 12. Rift crossing a stream at Pierce ranch, showing old and new fault scarps.

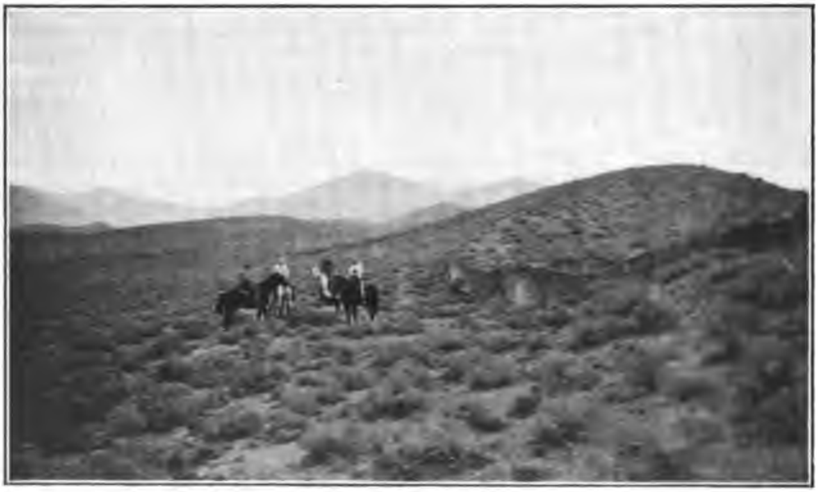

Fig. 13. South end of earthquake rift two miles south of end of Sonoma Range.

The major features of the topography of the area immediately adjacent to the fault or place of origin of the earthquake are shown on the accompanying map (Fig. 7), traced from the atlas [1] accompanying the report of the Fortieth Parallel Survey. The contour interval is approximately six hundred feet, and while on a small scale and broadly generalized, yet the general relations of the area most affected are well shown. In the atlas the mountain ranges are called the Pahute and Havallah Ranges, but as far as could be learned these names have never come into local use; and the names by which the ranges are known in Nevada have been used in the present paper.

The East (Humboldt) and Sonoma ranges are typical basin ranges, comparatively narrow, elongate ridges, rising rather abruptly three to four thousand feet above the valleys. Both ranges begin at the Humboldt River, and continue due south in marked parallelism for sixty miles. Here the Sonoma Range ends, but the East Range turns to the west somewhat and then continues southerly for many miles beyond. Both ranges are composed of a thick sedimentary series of Triassic age, according to Hague,[3] including limestones, quartzites, and slates; massive granites; rhyolites and basalts.

The valley between the two ranges is divided by a low transverse swell about thirty miles south of Winnemucca. The northern half is known as Grass Valley, and drains to the Humboldt River. The southern portion is Pleasant Valley, which drains to the south. Both are typical valleys of the Great Basin, with the long alluvial slopes of the bajadas descending from the mountains at either side and meeting at the center in small playas. Only at the southern end of Pleasant Valley is there a definite stream channel developed forty or fifty feet in depth.

The Sonoma Range south of Mount Tobin is composed almost exclusively of rhyolite and basalt, the rocks dipping to the east. North of Mount Tobin and including it the Triassic sediments are the prevailing rocks, and form a broad anticlinal-synclinal fold that extends across the pass at the bifurcation of the range. Further north the prevailing dip is to the east. As is the case in so many of the Basin ranges, the strike of the axes of the folds differs by a small angle from the trend of the range.

The western face of the Sonoma Range is an eroded fault scarp. The fault trace can be followed along the western base of the range across shoulders in the projecting ridges, by lines of hydrothermal action, and occasional remnants of slickensided surfaces. In Grass Valley a comparatively recent fault scarp, six to ten feet in height, can be traced along the base of the range. The scarp clings rather closely to the base of the range to the north, but gradually leaves it to the south, cutting through the alluvial slope near the range, until at the southern end it turns to the west and follows the base of the swell dividing the valleys. The hot springs noted on the topographic map are located at the base of this fault scarp. This is the fault line included by Russell[4] as one of the post-Quaternary faults in his monograph on the history of Lake Lahontan. As far as could be observed there was no movement along this scarp during the recent earthquake; but it is possible that it may have been the cause of the series of earthquakes that occurred in this valley about 1840, according to the stories told by the Indians to the early settlers.

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[3] Hague, Arnold: Geol. Exploration Fortieth Parallel, 2, 673-712. 1877.

At the north end of Pleasant Valley the old fault trace is obscure, and it is possible that it crosses the range at the pass and continues along the northern side of the east fork of the range. It begins to be more evident at the foot of Mount Tobin, and a branch extends back of the low spur offset from the main range at the Shell ranch. South of Mount Tobin it returns to the base of the range, and can be traced near the junction of the bajada and the mountain slope. South of the Siard ranch it climbs several hundred feet up the face of the range, and is marked by shoulders in the projecting ridges. At the Pierce ranch it is again at the base of the range, and continues with an occasional break back up the face of the mountain to the southern end, where it is lost under the deep alluvium. From its attitude as it crosses the higher elevations it is evident that the fault dips steeply to the west, and is a normal fault.

The recent fault scarp formed at the time of the earthquake follows the old fault line very closely. There is a decided tendency for the break to be somewhat further to the west as the scarp crosses the deeper unconsolidated deposits of the alluvial fans, leaving a thin wedge of the alluvium still clinging to the rock; but where the rift crosses solid rock the old and new fault traces are practically coincident.

The earthquake rift is first evident two miles north of Mount Tobin, where it appears as a vertical face four or five feet in height, following close to the junction of the bajada and the mountain slope, and disappearing opposite the Shell ranch. At the Shell ranch, which is located on a low spur from the main mountain range to the south, and about two miles west of Mount Tobin, the rift begins again as a number of small bifurcations in the alluvial slope to the north. These coalesce in a single rift as it crosses the spur, and form a single vertical face four feet in height, running just back of the cabin (Fig. 4) and continuing south across the meadow, where the sod has held the earth together and the rift is marked only by the cracks in the sod and the sudden drop of the surface of the meadow. From here on the rift gradually increases in height, and while occasionally breaking into two or more branches as it crosses the alluvial fans, it becomes more definite, until between the Siard and Pierce ranches it has a height of ten to fifteen feet, and appears from the center of the valley as if a newly constructed railroad grade had been run along the base of the range. This is well shown in the photograph (Fig. 8), taken a few miles north of the Pierce ranch.

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[4] Russell, I. C.: U. S. G. S., Monograph 11, plate 44, opp. p. 274.

The best and most accessible place to study the earthquake rift is at the ranch of Mr. W. L. Pierce. The ranch is located within a few hundred feet of the rift, and as the maximum displacement occurred near this locality, examples of practically all phenomena connected with the fault may be observed within a short distance. Beginning at the barn there is a fence that runs to the east across the fault rift and up the slope of the mountain side. A photograph (Fig. 9) was taken along the line of the fence about two hundred feet from the fault, and shows as closely as can be determined by eye that the fence was not laterally displaced but that the movement was entirely vertical down the dip of the fault. At the fault the fence was broken, and an open pit fifteen feet in depth exposed the rock surface at the bottom, giving an opportunity to determine the true dip of the fault. In the photograph (Fig. 10) looking to the north in the pit, the rock surface may be seen at the base of the post suspended by the broken wires of the fence. The surface is striated and covered with a thin layer of clay gouge developed by the movement along the fault. The striations incline less than five degrees to the north from the vertical, bearing out the evidence of the broken fence that the movement was almost exclusively vertical, and that there was practically no horizontal movement along the strike of the fault. The vertical displacement here, as measured, was twelve feet and five inches. The dip as taken on the rock surface was 54° due west. The horizontal separation of the vertical walls of the alluvium covering the fault plane was nine feet, which corresponds very closely to the distance calculated from the vertical displacement and the dip.

The cause of the usual vertical face of the earthquake rift is very evident. As the fault plane approached the surface along the base of the mountain range the thinner unconsolidated alluvium offered less resistance to the movement than the longer contact between the alluvial wedge above the break and the fault plane. As a result the break at the surface occurred a short distance to the west of the outcrop of the old fault, and a thin wedge of the upper edge of the bajada slopes still clings to the fault plane.

The development of pits similar to the one described is exceedingly rare along the rift. The reason for this is well illustrated by the photograph (Fig. 11) taken looking north at the Pierce ranch a few hundred feet north of the pit described. This shows the down-thrown side within fifty feet west of the rift. The tree at the right was originally vertical, as is the one at the extreme left. Its present posture shows that the surface layers of the soil tended to hang back as the deeper mass of the alluvium moved down the fault plane. At the surface the horizontal movement to the west was largely distributed through the secondary cracks developed in the surface layers of soil, and the rift filled with the caving of the disintegrated down-thrown block.

The features described give a clue to the common habit of the rift in dividing into two or more branches as it crosses the deeper alluvial deposits. Frequently one or more of the branches will die out, only to be replaced by another a short distance further down the slope. It is only where the rift closely follows the outcrop of the old fault line that it has a single continuous face.

Near the trees the rift crosses a stream which now flows across the scarp in a waterfall over ten feet in height. In the photograph (Fig. 12) the relation of the new scarp to the old fault line may be seen. The old scarp is along the rock surface at the waterfall. The rock is a silicified and cemented fault breccia, and has a striated and slickensided face. The new scarp is twenty feet to the west of the old scarp, and is formed in the alluvial fill of the valley. At the time of my visit the water of the stream was very muddy, and its flow was stated to be four times its normal flow at this time of the year. The additional water came from a crack in the gravel in the bed of the stream four miles up the canyon.

The rift continues to the south from the Pierce ranch, gradually decreasing in height, and clinging to the base of the mountain to the end of the range opposite the Cooper and Uniack ranch. Here it enters the low rolling hills of alluvium that cover the end of the Sonoma Range. It turns thirty degrees to the west, and fingers out in several branches running nearly due west that soon die out and disappear. The photograph (Fig. 13) is taken about two miles south of the end of the range, and shows the most prominent of the branches where it is still about four feet in height. A mile or two further all trace of the rift is lost, and as far as is known it does not appear again to the south.

The general position and course of the earthquake rift is shown on the map (Fig. 7) as a heavy line. It can be traced along the range as a continuous line for over twenty miles, and including the second rift at the base of Mount Tobin is over twenty-two miles in length. The movement that caused the earthquake was along the normal fault that has been largely responsible for the elevation of the southern half of the Sonoma Range, and indicates that the upward growth of the mountain has not entirely ceased. The central portion of the range is now ten to fifteen feet higher above Pleasant Valley, but owing to the lack of accurately determined bench-marks it can not be stated whether the mountain has increased in elevation above sea-level or not. The nearest line of accurate elevations is the line of precise levels run a few years ago by the Coast and Goedetic Survey along the right of way of the Southern Pacific Railroad, and it is possible that if this line were re-run some slight change might be noted.

EARTHQUAKE OF FEBRUARY 18, 1911

By Otto Klotz

There appeared recently a short paper by Prince Galitzin in *Comptes Rendus,* tome 160, p. 810, on the above earthquake which is of great interest to seismologists, and hence deserves a place in a seismological journal, which is my reason for offering the following translation together with some notes.

Earthquake of February 18, 1911.

(Galitzin, *Comptes Rendus,* **160**, 810.)

On February 18, 1911, a very violent earthquake took place in the Pamirs, and was generally registered at seismological stations. The seismograms obtained offer nothing in particular, and as more than four years have elapsed since then, this earthquake would certainly have been forgotten, if it had not been known later that on the same day and at the same hour an immense mountain slide occurred at Sarez in the Pamirs, which fell into the valley of the Mourgaf river and transformed it into a lake. Two years later Lieutenant Colonel Spilko of the Russian army visited Sarez and there studied in detail this remarkable slide, of which he gives a detailed map. He shows that on the 18th of February at 11^h 15^m in the evening Sarez was visited by a very severe earthquake, of intensity VIII, whereby 180 persons lost their lives in the district of Oroshor. Spilko gives as co-ordinates for the slide,

$$\varphi = 38^\circ\ 16'\ \text{N}, \qquad \lambda = 72^\circ\ 34'\ \text{E, Greenwich.}$$

This point is 3800 km. from the seismological station at Pulkovo. The Pulkovo seismogram gives for the beginning of the first phase of this earthquake the time,

$$P = 18^h\ 47^m\ 45^s\ \text{G. M. T.}$$

In applying the time required for the P waves to reach Pulkovo, $7^m\ 02^s$, we find the time of the quake to be $O = 23^h\ 17^m\ 55^s$, mean time Tashkent Observatory, which agrees with the time given by Spilko.

Let us now compare the distances Δ from the place of the slide to the different seismological stations with the epicentral distances Δ' deduced from the difference of times of arrival of the P and S waves.

Stations	Δ km.	Δ' km.	$\Delta - \Delta'$ km.
Tashkent	440	480	— 40
Baku	1960	1910	+ 50
Tiflis	2390	2430	— 40
Pulkovo	3800	3690	+110

The interagreement of Δ and Δ' may be considered very satisfactory. There can be no doubt then that the place of the slide and the epicenter fall together.

From the map or plan of Spilko, Mr. Weber, of the Russian geological survey, has determined the approximate value of the mountain mass which fell, as well as of the lowering, H, of its center of gravity. Accurate measures are of course not possible, yet one can fix approximately the order of magnitude of these quantities. Weber finds for M the enormous value of 7 to 10 billions of tonnes (milliard de tonnes). The limits of H are put at 300 to 600 meters.

These data enable us to determine two limits for the total energy, E, released by the slide in question. Putting g for acceleration, we have

$$E = MgH \quad . \quad . \quad . \quad . \quad (1)$$

Introducing into this expression the preceding values, and expressing the result in absolute C. G. S. units, we find the two following values,

$$E = 2.1 \times 10^{23} \text{ ergs.}$$
$$E = 6.0 \times 10^{23} \text{ ergs.}$$

This is certainly an enormous quantity.

One can now put the following question: Was the slide at Sarez the result or the cause of the earthquake recorded at so many distant stations?

To answer this question let us try to evaluate the energy released at the epicenter from the data obtained at the Pulkovo seismological station, which at the time was provided with aperiodic seismographs very sensitive to galvanometric registration. The energy E, freed at the epicenter, propagates itself towards the interior and along the surface of the earth. The analysis of the seismograms of distant stations shows that the energy manifested itself almost exclusively in the surface or long waves. Taking into account the damping or absorption of the seismic movement, we obtain for the total energy E, traversing unit surface at an epicentral distance Δ during the whole time of appreciable movement of the earth, the following expression:

$$E_1 = \frac{E}{2\pi\Delta^2} e^{-k\Delta} \quad . \quad . \quad . \quad . \quad (2)$$

where k is the coefficient of absorption. Calling ϵ the quantity of energy traversing unit surface at the observation station during unit time, V the velocity of the long waves, ρ the density of the superficial crust of the earth, and v_m^2 the mean of the squares of the velocity of a particle of earth during a complete oscillation, we have

$$\epsilon = \tfrac{1}{2} V\rho v_m^2. \quad . \quad . \quad . \quad . \quad (3)$$

Let a now be the amplitude of an earth particle and T the period of the corresponding seismic wave; we can then put

$$v_m^2 = \tfrac{1}{2}\left(\frac{2\pi a}{T}\right)^2 \quad . \quad . \quad . \quad . \quad (4)$$

a and T being in general variables; but, for a certain duration of time t, we may take the mean values as constant. Hence from equations (3) and (4) we may write

$$E_1 = \pi^2 V\rho \Sigma \left(\frac{a}{T}\right)^2 t. \quad . \quad . \quad . \quad (5)$$

The summation of Σ should be extended to the whole of the principal phase. If we designate the three components of the true movement of the earth particle by x_N, x_E, x_Z,

$$\text{then } a = \sqrt{x_N^2 + x_E^2 + x_Z^2}.$$

A detailed analysis of the seismogram could certainly give us the value of a, but for our purpose we may proceed in a more simple manner.

As the plane of oscillation of an earth particle changes constantly in direction, we may put for the mean $x_E^2 = x_N^2$. Furthermore, the theory of surface waves given by Lord Rayleigh and H. Lamb, shows that the vertical component of the movement of an earth particle should be in a constant ratio to the corresponding horizontal component. This ratio is according to theory 1.47, but the observations at

Pulkovo show that it is somewhat less, being 1.2. Hence the following relation is readily deduced:

$$a^2 = 4\ 88 x_N^2.$$

Combining equations (2) and (5), we have the total energy released at the epicenter,

$$E = 9.76\pi^3\Delta^2 e^{k\Delta} V\rho\Sigma\left(\frac{x_N}{T}\right)^2 t. \qquad . \qquad . \qquad . \qquad (6)$$

The reading of the seismogram at Pulkovo of this earthquake has given the following mean values of x_N and T for the different intervals of time t:

x_N	T	t
μ	s	min.
225	15	14
60	12	16
25	13	30
10	15	25

Hence

$$\Sigma'\left(\frac{x_N}{T}\right)^2 t = .00221 \text{ C.G.S.}$$

Furthermore

$$\rho = 2.8, \quad V = 3.5\,\frac{\text{km.}}{\text{sec.}}, \quad \text{and} \quad \Delta = 3800 \text{ km.}$$

Respecting the value of k, one may put it equal to .0004, if Δ is expressed in kilometers, for this earthquake, based on the observations at Pulkovo. Introducing these values into (6), and expressing the result in absolute units, we have

$$E = 4.3 \times 10^{23} \text{ C.G.S.}$$

Comparing this value deduced from the Pulkovo observations with the two limiting values of E found above, viz. (2.1 to 6.0) × 10^{23} C.G.S., we see that they are not only of the same order of magnitude, but approach each other numerically.

This unexpected result leads us then to the following conclusion: Whatever may have been the cause of the slide at Sarez, we may claim with a great probability of truth that the slide was not the consequence, but the cause of the earthquake of February 18th, which was registered at many distant earthquake stations. This earthquake presents to us an exceedingly interesting case, and unique as far as my knowledge is concerned, where we have directly the value of the energy released at the epicenter, which besides coincides here with the hypocenter itself.

This is the end of the translation; and now a word about Galitzin's formulae, before discussing the Ottawa seismogram of February 18, 1911.

It will probably serve a good purpose if we express the six equations in dimensions of mass, length and time, thereby showing too the inter-relationship of them. In the reduction we shall express each term first by its own dimension.

(1) $E = MgH = MLT^{-2}L = ML^2T^{-2}$, a fundamental expression in dimensions for kinetic energy.

(2) $E_1 = \frac{E}{2\pi\Delta^2}e^{-k\Delta} = ML^2T^{-2}L^{-2} = MT^{-2}$, energy per unit area.

(3) $\epsilon = \frac{1}{2}V\rho v_m^2 = LT^{-1}ML^{-3}L^2T^{-2} = MT^{-3}$, i.e., $= \frac{E_1}{T}$, or MT^{-3}.

The energy for unit area for unit time equals the whole energy for unit area divided by the time.

(4) $v_m^2 = \frac{1}{2}\left(\frac{2\pi a}{T}\right)^2 = L^2T^{-2}$.

(5) $E_1 = \pi^2 V\rho\Sigma\left(\frac{a}{T}\right)^2 t = LT^{-1}ML^{-3}L^2T^{-2} = MT^{-2}$, as in (2).

(6) $E = 9.76\pi^3\Delta^2e^{k\Delta}\,V\rho\Sigma\left(\frac{x_N}{T}\right)^2 t = L^2LT^{-1}ML^{-3}L^2T^{-2}T = ML^2T^{-2}$, as in (1).

The denominator in (2) is the area of the hemisphere of radius Δ.

In equation (3), v_m^2 must be distinguished from $v^2 = \left(\frac{2\pi a}{T}\right)^2$; the latter v pertains to the uniform velocity, while v_m^2 represents the mean of the squares of the velocity in the harmonic motion. It is the mean value of $\sin^2 \varphi$, for all values of φ, the angle of phase, from $\varphi = 0$ to $\varphi = 2\pi$. This mean value is equal to $\frac{1}{2\pi}\int_0^{2\pi}\sin^2 \varphi \, d\varphi$. The indefinite integral $\int \sin^2 \varphi \, d\varphi = \frac{1}{2}\varphi - \frac{1}{4} \sin 2\varphi + C$; therefore $\frac{1}{2\pi}\int_0^{2\pi} \sin^2 \varphi \, d\varphi = \frac{1}{2}$, *i. e.*, the mean value of $\sin^2 \varphi$ for a complete oscillation is $\frac{1}{2}$. The e in equations (2) and (6) is the base of Napierian logarithms. Equation (5) is obvious. The numerical coefficient 9.76 in equation (6) is obtained thus: as explained, $x_N{}^2$ is taken equal to $x_E{}^2$ and theoretically $x_Z = 1.47x_H$ (Poisson's ratio being taken at $\frac{1}{4}$), where x_H is the horizontal component and equal to $\sqrt{x_N{}^2 + x_E{}^2}$; hence $a = \sqrt{2x_N{}^2 + (1.47\sqrt{2}x_N)^2}$. Galitzin uses 1.2 instead of 1.47, therefore his $a^2 = 4.88x_N{}^2$, and the coefficient 9.76 follows.

In the summation of $\Sigma\left(\frac{x_N}{T}\right)^2 t$, all the terms must be expressed in centimeters and seconds respectively. The energy evaluated pertains only to the long waves, which as Galitzin states show almost exclusively the energy. Whatever the energy shown by the longitudinal and transverse waves is, it is small compared with the former. From our Ottawa seismogram it is about one-thirtieth of that of the long waves, so that the deduced energy should be increased by that amount.

The density 2.8 answers for the immediate surface, while for Wiechert's crust or shell the density is 3.2. As a matter of fact, we do not know to what depth the long waves are involved.

Now let us look at our record (bulletin issued) for that day, and we find a distant earthquake recorded giving

$$P = 19^h\, 04^m\, 44^s, \quad L = 19^h\, 23.7^m, \quad M = 19^h\, 35.5^m$$

the mean of the N and S components. From Galitzin's data we find the time of the quake $= O = 18^h\, 40^m\, 43^s$ G.M.T. Mohorovicic table gives for P for Ottawa, distance 10,200 km. $= 13^m\, 12^s$. Hence P should arrive at Ottawa at $= 18^h\, 53^m\, 55^s$. Zeissig's table for 10,200 km., $S - P = 11^m\, 07^s$. Hence S should arrive at Ottawa at $= 19^h\, 05^m\, 02^s$. We see therefore what we read on the seismogram as P was undoubtedly S, although there is a difference of 18^s. Again when we take $O = 18^h\, 40^m\, 43^s$ and the distance, scaled on a 30-inch globe, from Ottawa to Spilko's epicenter, as 10,200 km., and divide the latter by 240, the rate of propagation of the L waves per minute, we obtain 42.5^m as the elapsed time. Hence the L waves should arrive at Ottawa at $19^h\, 23.2^m$, which is practically identical with the observed value. It may be remarked that the L waves travel with constant velocity only in an isotropic medium along the surface. However, this condition does not obtain, and hence we find for different earthquakes with rays traversing different regions, some variation in the velocity, lying between the limits of 200 to 240 km. per minute. On our velocity curves for *P*, *S*, and *L*, used for graphical application of recorded earthquakes, we have two straight lines for *L*, with respective velocities of 200 and 240 km.

The above record is then of the Pamirs earthquake. Knowing now the distance to the epicenter, 10,200 km., it is easy to reason *post facto* that it is somewhat improbable that we should easily be able to read an *i P*, since the angle of emergence for that distance is approximately 69°, and hence the horizontal component very small. However, again examining the seismogram for that day we find a very small, but sharp, *i* at $18^h\,54^m\,14^s$. This is 19^s later than our deduced *P*. Microseisms somewhat interfere in detecting an emersio for *P*.

We shall now evaluate the energy at the epicenter on the lines of Galitzin's investigation, utilizing our data from the seismogram of February 18, 1911. In the report of the Chief Astronomer for 1911 on page 23 will be found our value for absorption determined from the Turkestan earthquake on January 3-4 of the same year, and not so very far from the February earthquake, *k* being = .00032. The distance as above is 10,200 km., and for the density of the crust we retain the value of 2.8, which is approximately the mean of the various rock constituents (Smithsonian tables).

We have from the seismogram:

Amplitude x_N μ	Period T s	Interval t min.
20	30	7
40	20	11
30	16	3
20	12	16
10	16	25

From which we find

$$\Sigma\left(\frac{x_N}{T}\right)^2 t = .00006713 \text{ C.G.S.}$$

We were not provided with a vertical component seismograph in 1911, but the recent earthquake of September 7, 1915, has enabled us to obtain a ratio between the vertical and horizontal components for the long waves. This we find to be 1.40, instead of the theoretical 1.47, or Galitzin's observed value of 1.2. Hence the numerical coefficient 9.76 in equation (6) becomes 11.84.

Substituting the above values for Ottawa in equation (6) we find $E = 7.0 \times 10^{23}$ ergs C.G.S. Galitzin's similarly deduced value for the same quantity is 4.3×10^{23} C.G.S. Although the agreement is fairly satisfactory, yet it must be admitted that the reading of the seismogram upon which the result depends is not so simple a matter. In a good tectonic earthquake, distant say 6000 or 7000 km. or less, there would be no question in reading P and S; but when it comes to reading L, the various periods, their duration, their amplitudes, the different magnifications to apply,—we are plunged, if not into uncertainties, into complexities and perplexities, which are not likely to receive identical interpretation from experts. It is not desired to convey the idea that the results would be unreliable, but that the results would be discordant while probably of the same order of magnitude. In the above evaluation it may be pointed out that the absorption factor plays an important part, yet its value is known only within fairly large limits, as was pointed out in my report for 1911 referred to above,—and it is not necessarily a constant.

The value of Galitzin's investigation lies in the fact that he gives us some definite information, from Weber's figures, of the actual earth mass movement as 2.1 to 6.0×10^{23} ergs. It remains then for all seismologists who have a good record of the earthquake, and who know the constants of their instruments, to see whether the seismograms tell a similar story of the energy released in the Pamirs on February 18, 1911. It is hoped that the reproduction of Galitzin's article will stimulate the dynamic investigation of well recorded earthquakes.

In closing we may refer to the largest observed rock slide or rock fall in Canada, at Frank on April 29, 1903, when 70 lives were lost, and of which an official report was published. From it we find that the mass displaced was 40,702,000 cubic yards as determined from the old and new contours of the mountain. From the measurement of the debris the estimated mass was 36,000,000 cubic yards. In this latter report reference is made to two notable slides in Switzerland: the Elm slide of 12,000,000 cubic yards, when 84 houses and 115 lives were lost; and the Rossberg slide of 51,000,000 cubic yards, when four villages were destroyed and 457 lives lost. The Pamirs mountain fall (Bergsturz) was 3,270,000,000 cubic yards!

ON A POSSIBLE CAUSAL MECHANISM FOR HEAVE-FAULT SLIPPING IN THE CALIFORNIA COAST RANGE REGION.[1]

By Harry O. Wood.

This study is a speculation in regard to a causal mechanism for such peculiar heave-fault slips as that which occasioned the 1906 earthquake in California. It has particular reference to the Central California Coast Range region. The hypothesis advanced rests upon the facts, (*a*) that it depends upon true tendencies, however sufficient or insufficient these may be quantitatively; and (*b*) that it offers explanation, in matters of detail and sense, of the phenomena observed. To find such explanation has proved very puzzling to all who have given thought to the matter.

It has been necessary to introduce several assumptions into the study. None of them, taken alone, is violent. Some may possibly be of unprovable, though of reasonable character. In developing the view, where much is conjectural, it has seemed necessary to proceed from step to step as though at each stage only slight degrees of doubt remain as to the soundness of the thesis. Of course there is doubt,—many will think grave doubt,—as to the quantitative sufficiency of the forces invoked to produce the effects suggested. Owing to his remoteness from scientific reference libraries, the writer has had no opportunity to consult certain studies which bear upon important aspects of the problem.

The theory of isostasy, though perhaps hardly to be considered as established beyond question, has recently received very strong support in several thorough geodetic studies.[2] As Hayford views it: "It is certain that readjustment towards isostasy has been in progress during the period covered by geologic record."

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[1] Read at the San Francisco meeting of the Geological Society of America, August 1915.

[2] "The Figure of the Earth and Isostasy from Measurements in the United States," by J. F. Hayford, U. S. C. & G. S., 1909.

"Supplementary Investigation in 1909 of the Figure of the Earth and Isostasy," by J. F. Hayford, U. S. C. & G. S., 1910.

"The Relations of Isostasy to Geodesy, Geophysics and Geology," by J. F. Hayford, *Science*, N. S., 33, 199-208, 1911.

"Recent Gravity Work in the United States," by William Bowie, *American Journal of Science*, **32**, 101-114, August 1911.

This theory is assumed here. Readjustments in conformity with it, due to disturbances of balance brought on by progressive erosion and deposition in the neighborhood of the province, are considered, tentatively, as the important prime movers in crust-strain building in the California region. A study by Ransome,[3] chiefly in relation to the Great Valley of California, reached a conclusion somewhat adverse to this. However, since the time of his writing, the doctrine of isostasy has been more strongly supported than ever before; and more intimate readjustments are now looked for than formerly in response to transfer of load from one region to another.

For example: "The geodetic observations show that the isostatic compensation under the United States is nearly complete. It is not merely a compensation of the continent as a whole; it is a compensation of the separate, large, topographic features of the continent. There is an excess of mass in some columns and a defect in others; but the evidence indicates that the average excess in the areas of under-compensation is properly represented by a stratum only 250 feet thick, having the same density as the surface portion of the earth (2.67). Similarly, the average defect of mass in the areas of over-compensation corresponds to a stratum only 250 feet thick."[4]

And further: "From the evidence given by deflections of the vertical, the conclusion has been drawn that in the United States the average departure from complete compensation corresponds to excesses or deficiencies of mass represented by a stratum only 250 feet thick on an average. The gravity determinations indicate this average to be 630 feet instead of 250 feet. In neither case is the average value determined or defined with a high grade of accuracy. The difference

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"The Effect of Topography and Isostatic Compensation upon the Intensity of Gravity," by J. F. Hayford and William Bowie, U. S. C. & G. S., 1912. Special Publication No. 10.

"The Effect of Topography and Isostatic Compensation upon the Intensity of Gravity," (Second Paper), by William Bowie, U. S. C. & G. S., 1912. Special Publication No. 12.

"Isostasy, A Rejoinder to the Article by Harmon Lewis," by J. F. Hayford, *Journal of Geology*, **20**, No. 6, 1912.

"Isostasy and the Size and Shape of the Earth," by William Bowie, *Science*, **34**, 697-707, May 15, 1914.

[3] "The Great Valley of California: A Criticism of the Theory of Isostasy," *Bulletin of the Department of Geology, University of California*, **1**, No. 14, 1896

[4] Hayford, *Science*, **33**, 200, Feb. 10, 1911.

between the two determinations of the average value is therefore of little importance. The determination given by the gravity observations is probably the more reliable of the two. Each determination is significant mainly as showing that the isostatic compensation is nearly perfect."[5]

Also Hayford predicted that "future investigations will show that the maximum horizontal extent which a topographic feature may have and still escape compensation is between one square mile and one square degree."[6]

The peculiar fling which operated along the fault-slip in 1906 led those who investigated it to considerations in regard to the distribution of elastic crust-strain which soon found clear utterance in the elastic rebound theory of slipping elaborated by Professor H. F. Reid.[7] So well does this explanation fit the observed facts that little or no adverse crticism has been offered. The present study depends upon it as a secondary, but important, mechanism in relation to faulting, particularly in this region.

In offering the ideas presented here, there is no intent to exclude from ultimate consideration the operation of other agents responsible for strain building. It is intended merely to follow out logically the consequences of intimate, isostatic readjustments modified as may be, at the time of fault-slip, by elastic rebound in this restricted region. No attempt is made to undertake a minute analysis of erosion and sedimentation, or to approximate the quantities of these or of the stresses or strains considered to result. Merely a general sketch of the idea is intended.

The broad lines of the geomorphy of California are well known. An abrupt, mountainous coast extends in a N.NW.–S.SE. direction from Cape Mendocino to Point Arguello. North from Mendocino the coast line, still mountainous, trends north. From Point Arguello it trends in general E.SE., still preserving its mountainous character.

Lying east from the Coast Ranges and traversing about three-quarters the length of the province is the Great Valley of California, more than 400 miles long in the general N.NW.–S.SE. direction, and from fifty to seventy-five miles wide between the foothills of the Coast Ranges and those of the Sierra Nevada.

East of this great, diastrophic trough rises the mountain crust

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[5] Bowie, Special Publication No. 12, U. S. C. & G. S., 1912.

[6] "Supplementary Investigation" etc., U. S. C. & G. S., 1910.

[7] "The Elastic Rebound Theory of Earthquakes," *Bulletin Department of Geology, University of California*, **6**, 413-444, No. 19, 1911.

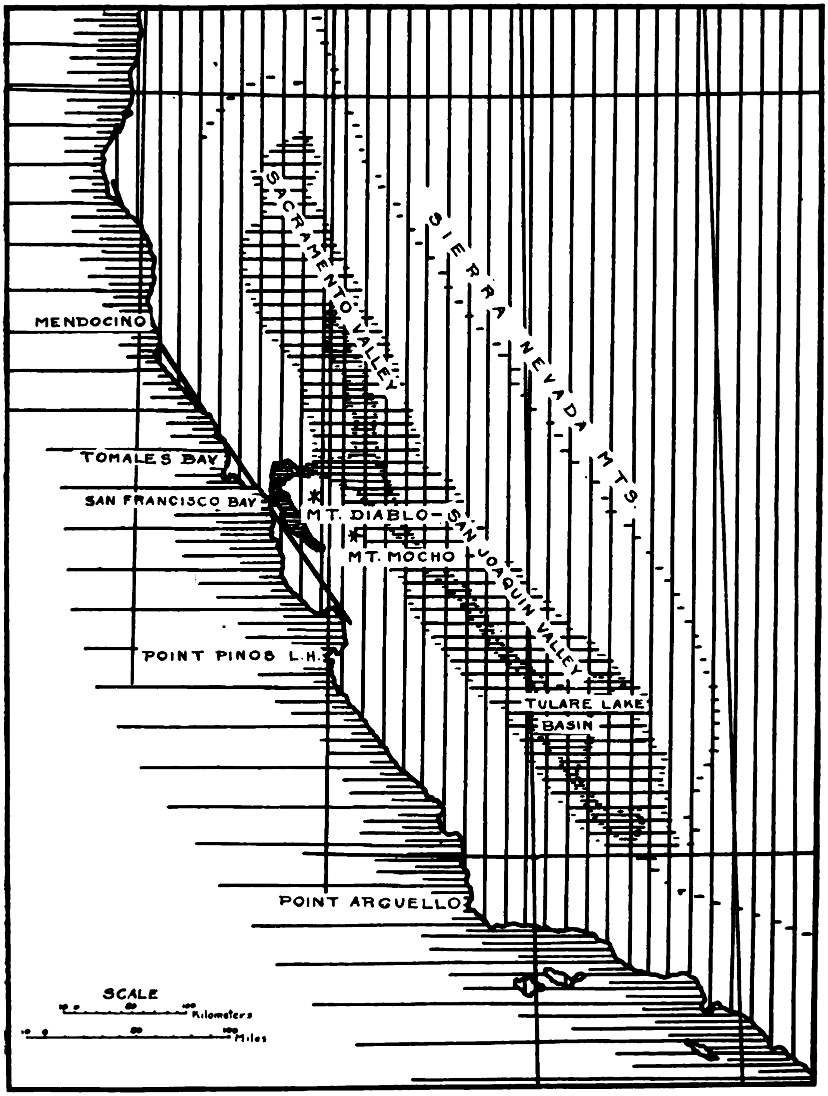

Fig. 1. Map of California. Vertical bars indicate land area. Horizontal bars indicate and differentiate regions of loading. Diagonal line near San Francisco Bay indicates fault-trace, 1906 movement.

block of the Sierra Nevada, merging at the north with the mountains of the Cascade and Klamath systems; and at the south conjoining with the mountains of the Coast Ranges and those of Southern California.

The gradual southwestward slope of the Sierra Nevada is deeply and intricately carved by many streams, which have carried the products of erosion into the Great Valley, there to be assorted and redistributed by the Sacramento and San Joaquin rivers. A minute study would be required to ascertain and measure the distribution of this burden of sediment. We may assume with little doubt that the burden deposited within the valley itself has been progressively greater than the amount removed by erosion. Also it is probable, that in the long course of time the heaviest load of sediment, within the valley, has been laid down along the anastomosing courses of the trunk streams, increasing in burden toward their junction and about their entrance into San Francisco Bay.

However, a very great burden of this sediment must have been carried from the Great Valley into San Francisco Bay, partly to be dropped in that depression, partly to be swept on out through the Golden Gate to be dropped on the adjacent floor of the sea. It is not improbable that the amount of sediment thus deposited on the floor of the sea and transported by ocean currents along the coastal margin may have been far greater than the deposit in the troughs of the Great Valley and the Bay.

Some such distribution as this has been in progress since the uplift of the Sierra began.

From the Coast Ranges fewer and smaller streams contribute to the Great Valley a relatively small part of the sediment to be worked over and redistributed toward the sea.

Also leading into the Pacific from the Coast Ranges are many small streams and several small rivers. These have carried the waste of the western slope out to the adjacent ocean floor, there to be worked over by the littoral agencies and commingled with the waste swept out through the Golden Gate.

An intimate study of this denudation and correlative sedimentation, with regard to the isostatic consequences, would discover great complexity. In a broad way, however, we may recognize, during the present cycle, two areas of progressive loading: (1) the Great Valley, within which we note a general tendency to concentration of load along the trunk streams, particularly toward their junction, and in and about San Francisco Bay; (2) a broad marginal tract along the whole coast and especially on the ocean floor adjacent to the Golden Gate, where the contribution from the Sierra is first laid down. Also, within the Great Valley there is, probably, an area of relatively heavy loading in and around the Tulare Lake Basin. To simplify the following presentation this area may be neglected. To consider it would complicate, but would not effect adversely, the hypothesis developed here.

Conversely, an area of great progressive denudation in the broad slope of the Sierra Nevada, and an area of lesser denudation in the Coast Ranges, may be recognized.

From the theory of isostasy we should expect the areas of deposition to be progressively down-warped, and those of denudation to be up-warped, which would involve creep in the plastic depths from the down-warping regions toward the up-warping tracts.

In this connection Hayford writes: "Gravitation tends to produce a deep undertow from the regions where deposition is taking place to the regions where erosion is in progress, in the direction opposite to that of the surface transfer of material." [8]

Also: "Hayford puts the undertow comparatively near the surface, where it is conceded that it would be effective in producing folding. . . ." [9]

Further: "If a layer of material 1,000 feet thick, is eroded from one part of the earth's surface and deposited on another part . . ." changes in pressure, density, temperature and chemical conditions will follow, from which Hayford concluded that "horizontal compressive stresses in the material near the surface above the undertow are necessarily caused by the undertow. For the undertow necessarily tends to carry the surface along with it, and so pushes this surface against that in the region of erosion." [10]

The level of the undertow, or sub-crustal creep, is considered to be much nearer the surface than the level of isostatic compensation. Hayford concluded that the most probable depth of the level of isostatic compensation, for the United States and adjacent areas, is 122 kilometers. Bowie's correlations of topography and isostasy with the intensity of gravity are in accord with this. Wiechert [11] concluded from a consideration of the length of earthquake waves, that there is a plastic stratum, the "Magmaschicht," at the depth of 31.5 kilometers. The temperature gradient [12] also indicates a similar depth for the zone of plasticity. In the province here discussed such a depth is small by comparison with the lengths and breadths of the areas considered to be involved in isostatic readjustments of equilibrium.

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[8] *Science,* 33, 203, Feb. 10, 1911.

[9] *Journal of Geology,* 20, 573, No. 6.

[10] *Science,* 33, 203-206, Feb. 10, 1911.

[11] "Vorlesungen über Seismometri," Galitzin-Hecker's translation, p. 149, 1914.

Of course, density as well as topography is a factor in producing or maintaining isostatic balance. However, on the assumptions of either 113 or 122 kilometers as the most probable depth of the level of isostatic compensation in turn adopted by Hayford as conclusions from his successive studies, the residuals of deflection of the vertical point to so complex and alternating a distribution of greater and less densities beneath small neighboring portions of the Coast Ranges and the Great Valley, that even a qualitative consideration of their bearing on this study is impracticable. The supplementary gravity investigations by Bowie, while indicating a general defect of mass practically throughout California, and according with the indications from deflection of vertical, do not permit a sufficiently intimate delineation of the anomalies to be of service here, even if of real significance. But Bowie expressly states that his investigations do not indicate any general tendency to defect of gravity in regions of erosion, or excess of gravity in regious of deposition. Moreover, as Gilbert [13] has pointed out, anomalies of gravity may be interpreted in several different ways; so that, until we have better and more detailed knowledge of them, we can lay no emphasis upon any agreement or disagreement of their distribution with the theses of this or similar studies.

In the Central Coast Ranges, particularly in the neighborhood of San Francisco Bay, it is to be noted that a long, narrow tract subjected to relatively little denudation lies between two elongate areas upon which a heavy burden is progressively falling, with a tendency for the greatest load to be concentrated in depressions around and within the Bay. For this part of the Coast Ranges, then, it is possible and even probable that a tendency to down-warping, due to the positive down-warping of the adjacent tracts of heavy sedimentation, may much exceed the tendency to up-warping due to the slight denudation.

We have now partly indicated, partly postulated, a region of down-warping across which extend two practically continuous, long, narrow tracts which are subsiding less rapidly than the rest, and undoubtedly less and less rapidly as we go outward from the center along their axes.

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[12] *Op. cit.*

[13] "Interpretation of Anomalies of Gravity," by G. K. Gilbert, Professional Paper 85-C, U. S. G. S., 1913.

Granting this, it is a consequence of the theory of isostasy that the sub-crustal, plastic material must be creeping away in all directions from this subsiding region, in the vicinity of San Francisco Bay.[14]

However, on the present hypothesis, it must be creeping less rapidly from beneath the Coast Range tracts than from the adjacent strips undergoing sedimentation. Moreover, since there must be a tendency for sub-crustal matter to creep from beneath both the sub-oceanic coastal tract and the Great Valley fluviatile tract toward positions under the adjacent Coast Range tracts, which nevertheless we postulate to be positively down-warping, there must be little or no actual outcreep from beneath the Coast Range strips in the directions perpendicular to their N.NW.–S.SE. axis. This should hold also for long, narrow portions of both the tracts of sedimentation lying adjacent to the sinking portions of the Coast Range,—the portions lying to the west of the line of most rapid subsidence in the Great Valley and to the east of the corresponding line along the coast.

Hence we may imagine a considerable area, probably of very elongate oval shape, with the major axis stretching N.NW.–S.SE., centering around San Francisco Bay, from under which little or no W.SW. or E.NE. outcreep occurs, despite its progressive subsidence.

On the other hand, since no obstacles to outcreep along the major axis, analogous to those mentioned above, claim attention, such outcreep from under this elongate central area should be looked for along the directions of its major semi-diameters. If found in these directions it then should be greatly accentuated, partly as a natural hydrostatic consequence, partly because of the constraint exerted upon the sub-crustal matter to creep, if at all, to the N.NW. and S.SE. between the two lines of most rapid down-sinking which traverse lengthwise the Great Valley fluviatile and the sub-oceanic coastal strip.

We may thus think of the net result as a much more considerable outcreep from beneath the vicinity of San Francisco Bay in directions parallel to the trend of the Coast Ranges than in directions perpendicular to them. In such a broad, general way this applies to the whole Central California Coast Range province.

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[14] Without developing this specialized treatment, Professor Reid referred to isostatic undertow in a consideration of "a possible origin of the deforming forces" on p. 27, 2, pt. I, Report of the California Earthquake Commission, 1910.

This creep must exert traction upon the superjacent crust, tending to drag it away from the neighborhood of San Francisco Bay, to the N.NW. and to the S.SE. If, upon careful consideration, some central point could be located from which all the traction vectors would be found to radiate, there would appear a strain-configuration of

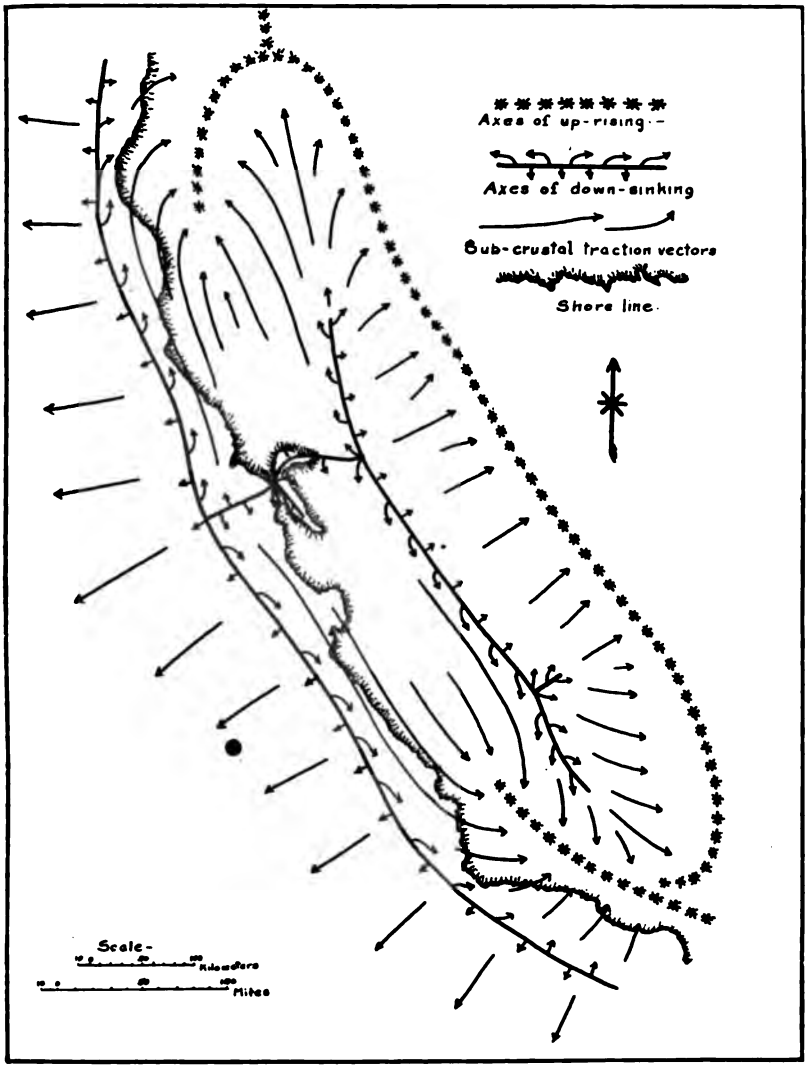

Fig. 2. Exhibit of tendency to surface distortion.

simple extension in the crust in all directions away from the origin point; though with different tension in different directions. Such a balance of action, and such a configuration, are extremely unlikely.

For no such balance among the forces of traction is logically to be expected in a region in which irregularly different rates of down-warping prevail in different places unsymmetrically distributed. A brief digression may serve to exemplify this.

Suppose the Coast Range north of Mendocino to be, not down-warping, but up-warping. Obviously there will tend to creep in underneath it matter from under the north part of the Great Valley, and from the adjacent submarine coastal tract, as well as from the Coast Range strip further south. A glance at the geographical configuration will show that the increep beneath this area from under the Coast Range tract would tend to be lessened, or checked, by its confluence with the two other increeps and that, *a priori*, the direction of the resultant creep would be indeterminate. Even more complicated might be the situation under the territory on the margin of the south end of the Great Valley, where the Tulare Basin accumulations would be likely to interfere with the symmetry of the sub-crustal creep.

These traction forces would have the effect at any place, near to but not at the center of the region, of a distorting couple with or without a translatory component. If such be the actual status, there would thus arise a horizontal shearing stress. For a long time after its initiation little result might be expected; but, being steadily maintained, ultimately a shearing strain would be built up extending over a great part, if not all, of the province. And in the course of time this strain might approach and reach the limit of strength of the rock crust.

In some restricted locality, the strength of the rock would be exceeded, and fracture would occur; and with it, elastic rebound-slips toward an earlier configuration. This would afford a partial and temporary relief in the restricted locality; but, in all probability, the general shear over the region as a whole would be affected only slightly; certainly, it could not be relieved completely. In any event, so long as the traction continued to act, the shear would continue to grow; and thus fracture and slipping, with rebound, would recur, either in the same zone, or in others. For in this way a series of fault zones, characterized by heave-displacements, might arise.

Without contending for the quantitive sufficiency of the forces of traction here supposed, the writer wishes to point out that, granted an over-strained regional shear, such slip-fault rebounds, like that of 1906, may reasonably be considered as snappings of small magnitude within the overstrained crust; and that the occurrence of such need not relieve, save in slight degree, the general regional strain. Such effects may easily be produced in the weaker parts of a large sheet of stiff gelatine subjected to increasing shear, without effecting any notable decrease in the growth of the strain. But, of, course, in the earth's crust we are confronted with a very long time-factor and the consequent, unknown degree in which elastic fatigue, permanent set, and above all, viscosity, enter. Some, doubtless, will think these factors of sufficient adverse influence to invalidate the hypothesis here developed.

In this general consideration of the shear, due to isostatic subcrustal traction, nothing has been said as to the direction of it beyond indication of the tendency to greater creep, and consequent stretching, N.NW.-S.SE.

The existence of a horizontal shear was demonstrated by the fault slip of 1906. This displacement is best explained by elastic rebound from an over-strained configuration, whereby the crust adjacent to the fault was flung relatively to the N.NW. on the western side and to the S.SE. on the eastern side, by an amount of 21 feet at maximum. Peculiar topographic features were then developed, or rejuvenated, which teach with certainty (*a*) the fault-slip origin of older features in the same zone, and (*b*) by the geographical distribution of similar features, the existence of several of this kind of zones within the province. These fault zones are regarded by the writer as evidence that the shear is regional, and that it has long been maintanied near to the critical strength of the crust.

Let us now refer to the results of the geodetic study by Hayford and Baldwin of the region affected by the fault slips of 1906:[15]

These show:

(1) That the line joining stations on Mt. Diablo and Mt. Mocho did not undergo any change of direction, or of length.

(2) That "there was no appreciable change in the relations of these two stations to certain others nearer the fault"; that is that there was little or no distortion in the neighborhood of this line. It was therefore assumed that no discernible movement of these stations had occurred; and for similar reasons the writers thought that no discernible movement of these stations had occurred earlier. How-

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[15] Appendix No. 3, Report for 1907. U. S. C. & G. S., 1908.

ever, it was pointed out by Professor A. C. Lawson[16] that a movement (supposed southeastwardly) of the Diablo-Mocho line as a whole was not precluded by the geodetic evidence at hand, and that certain considerations of geology, and of elasticity, together with the available measures of surface movement, would point to such an interpretation. In large part the measured displacements were, in this view, thought to come about by a slow creep of the crust, building elastic strain.

It was shown, however, that the region around about the Mocho-Diablo line has undergone practically no discernible distortion since the first precise surveys, whether it has suffered translation or not.

On the other hand, between the survey stations on the coast at Tomales Bay and at Point Pinos Lighthouse there occurred between the earliest surveys in the 1850-60 decade and that completed in 1907 a total stretching of over ten meters. The distance between these stations is about 250 kilometers, making roughly a total elongation of one part in 25,000 in less than sixty years. Referred to the unmoved base-line these displacements were to the N.NW. at Tomales Bay and to the S.SE. at Point Pinos Lighthouse, 5.32 meters in the first case and 5.89 meters in the second case.

Both these stations are west of the fault where elastic rebound undoubtedly occurred in 1906. Except as somewhat modified by this latter complication, this geodetic finding demonstrates more rapid crustal creep away from San Francisco Bay along the coast margin than near the Great Valley margin, which accords with the view here developed. It is evident that traction would tend to build a shearing strain of the same kind, and direction, as that actually deduced from the fault-slip displacements.

The amount of stretching apparently indicated by the geodetic measurements may be in excess of the true stretching accomplished by creep in sixty years, owing to the nature of the shear, and the sense of fling of the rebound. This latter effect would presumably be greater at Tomales Bay than at Point Pinos, because the former is much closer to the fault. In other words, the stations may have been flung apart by a small amount in addition to the amount by which they had been separated by creep. If we exclude this, the measurements would indicate a traction probably more rapid than the forces here invoked could be expected to produce, even though integrated in large measure into the coastwise directions as suggested above.

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[16] Report of the California Earthquake Commission, 1, 147-151, 1908.

Nevertheless the geodetic measurements show that a movement of the surface has been going on, transferring points along the coast at the north of San Francisco Bay to the N.NW. and at the south of the bay to the S.SE more rapidly than points further inland; and the fault-slip showed that a shear exists such as might be produced by this movement. This shear is consistent in kind and direction with that which might arise from long-continued isostatic responses to the prevailing disturbance of balance in this province.

To establish a causal relationship of the kind here suggested, or to disprove it, would require a knowledge of the amount and distribution of the sedimentation, and an analysis and measurement of the isostatic responses. Neither data nor methods now exist well adapted for so refined a study; and we must be content to point out that the affirmative view is a logical consequence of the isostatic theory.

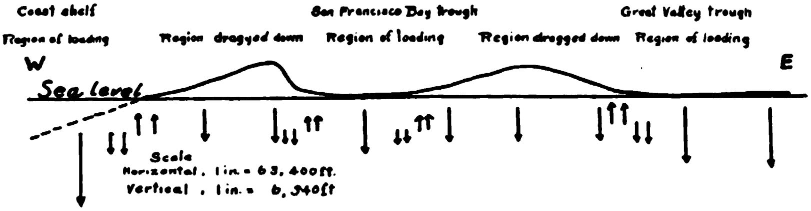

Fig. 3. Generalized section across the Coast Ranges near San Francisco Bay. Differential subsidence across the entire section indicated by large vectors. Minor and local, acute, vertical shear indicated by smaller vectors

Some further facts of observation are concordant with the implications of the hypothesis, and, therefore, tend in some degree to support it. In the Coast Ranges, particularly near San Francisco Bay, there are drowned valleys, which point to recent, and probably progressive, subsidence. In spite of this, raised beaches of slight and irregular elevation, and usually of small extent, also occur, apparently contradicting the drowned-valley indications. The hypothesis not only explains and harmonizes these features, but requires their coexistence.

We have supposed the down-warping of the Coast Ranges in this neighborhood to be at a less rate than that of the adjacent submarine and Great Valley sedimentation tracts. This positive, general sinking would account for, and require, the drowned-valley phenomena.

But if the adjacent lateral territory sinks faster than the mountain belt, a vertical shearing strain will develop locally along the coast and the Great Valley margin. If this became sufficiently acute and so were relieved by minor, local faults, the fling of the rebound would in every case tend to uplift the margins of the mountain tract and downthrow the margins of the submarine and Great Valley areas.

Besides the marine terraces, similar features, having of course, different physiographic expression, are to be seen along the western margin of the Great Valley. Since the line of acute shear would not follow with fidelity the indentations of the coast line, or of the junction of foothills and valley floor, minor apparent discrepancies might be expected. Therefore, whether this action is competent or not, it is at least plausible and expectable, and to some extent support is given to the hypothesis.

Though less pertinent, the following phenomena are of interest in this connection:

There is strong suggestion of recent, and probably progressive, uplift along the eastern scarp of the Sierra. There is further physiographic suggestion that the back of the Sierra is broken in the vicinity of Mammoth Pass, that the range is thus converted into two crust blocks, both of which are still rising and tilting to the west and north, the southern at the more rapid rate in both respects. But it is very difficult to substantiate this latter suggestion.

The idea is to some slight extent supported by the circumstance that the places of origin of a considerable group of earthquakes are so distributed along a line trending east and somewhat north from the region of San Francisco Bay as to suggest an action of bending, or faulting, or both, in the depths about an axis in this direction. This might be expected if the southern Sierra were rising faster than the northern, and were rising faster at its southern end.

It is interesting to note in considering this possibility that the map, illustraton No. 4, accompanying Bowie's later study, entitled "Effect of Topography and Isostatic Compensation upon the Intensity of Gravity (second paper)," which shows the "Lines of Equal Anomaly for Free-Air Method of Reduction," exhibits a closely crowded, parallel spacing of lines of plus anomaly extending from the region of San Francisco Bay to the region of Carson City. No emphasis can be placed upon this correspondence, however, for the map, No. 18, accompanying the earlier paper on the same subject by Hayford and Bowie, which shows the lines of equal anomaly for the same method, does not even suggest such an arrangement. The gravity stations were few and the later map is presumably the better approximation. But, on the other hand, in both papers the free-air method of reduction, upon which the anomaly maps mentioned were based, is relegated to a subordinate place by both authors, who give preference to a newer method of reduction. At the close of the second paper Bowie remarks: "The new method of reduction is very much nearer the truth than either of the two older methods of reduction." These facts, however, do not rob the correspondence of all significance.

So far as all this goes, it is concordant with the expectable action of the denudation, sedimentation, and consequent subterranean creep from under the Great Valley, particularly if the subsidiary area of sedimentation in the vicinity of Tulare Lake is important enough to consider. In the presnt cycle, this is a bolson from which no sediment is carried to the sea.

Hence from under the Great Valley, especially from (*a*) the neighborhood of the confluence of the Sacramento and San Joaquin rivers, and from (*b*) the neighborhood of the Tulare Lake Basin, we would expect the creep toward and under the Sierra blocks to be comparatively rapid. East of the Sierra there is no sedimentaion block comparable with the Great Valley. Hence this creep would have little or no tendency to be diverted along the N.NW.-S.SE. course. This creep in under the rapidly degrading Sierra blocks, would tend to accelerate their uplift and tilting to the north (and west); for the crest region at the extreme east is undergoing the most rapid degradation, and the south end of the northern block lies almost due east of the river confluence, while the south end of the southern block lies east and a little north of the Tulare Basin.

While no emphasis can be laid upon these concordances, still they are, at least, not adverse to the hypothesis here considered.

To discuss faulting, and sub-crustal tractions, due to action beyond the eastern base of the Sierra, is out of place here, especially as it would necessarily involve the consideration of other, probably greater, factors than local isostatic tractions, and so would have relatively little bearing on the present question.

In conclusion it may be said that: If the action described is real, it would continue uninterruptedly for long intervals of time, while given geographical configurations remained substantially without change. At certain critical epochs changes in configuration might be effected comparatively rapidly, giving effect almost suddenly to new relationships. To view the hypothesis as unfavorably as possible, we may assume at the beginning of such a new isostatic cycle, little or no rock strain in the region. Disturbances due to transfer of load would soon initiate tractions which, though of slight effect for a long interval, would operate constantly, and so produce accumulated strain; and this would evenually induce elastic strains in the surface rocks, and maintain them at or near the breaking point, so that the additional action of any of the recognized trigger forces might be expected to produce fracture with rebound, instead of slow change of form. That the supposed action is quantitatively sufficient to produce such a shear as is actually discovered to exist is a possibility which cannot be dismissed lightly. Precise measurements and careful analysis may demonstrate its incompetency, but its ceaseless action through geographical cycles entitles it to careful consideration.

Hawaiian Volcano Observatory,
April 8, 1915.

THE EARTHQUAKES OF OCTOBER 7, 1915, IN CENTRAL CALIFORNIA.

By E. F. Davis

This group of shocks comprised two moderately severe earthquakes, two of slight intensity, and a number of instrumental earthquakes, not perceptible to human beings. The first earthquake of the group was the most severe and represented the principal disturbance, the others being merely its after-shocks.

The first earthquake occurred at $9^h\ 25^m\ 42^s$ p.m. (P.S.T.). All observers at Berkeley agree that the shock began abruptly with a quick lurch of the ground, there being no preliminary movement. This is shown also by the instrumental records (figures 1, 2, and 3).

The force of the first impulse threw the writing-pens of the Bosch-Omori seismographs off the drums, so that no records of this earthquake were written by these instruments. While the horizontal components of the first earthquake were too strong for satisfactory registration by the more sensitive instruments, excellent records were obtained by the Omori tromometer. Figure 1 is the record of the vertical component obtained on the Wiechert seismograph. Figure 2 is the record of the east-west component, and figure 3 the record of the north-south component, both written by the Omori tromometer. The earthquake was strong enough to start the Marvin strong-motion seismograph, and a partial record was obtained on that instrument.

The maximum movement of the ground in the horizontal compon-

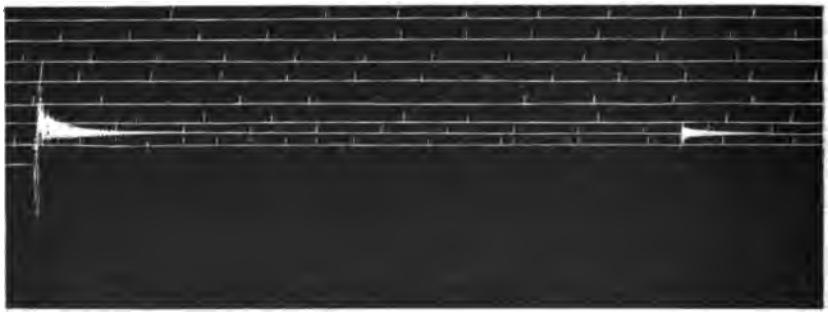

Fig. 1. Records of Vertical Components as registered by Wiechert Seismograph. Berkeley, Cal., October 7, 1915.

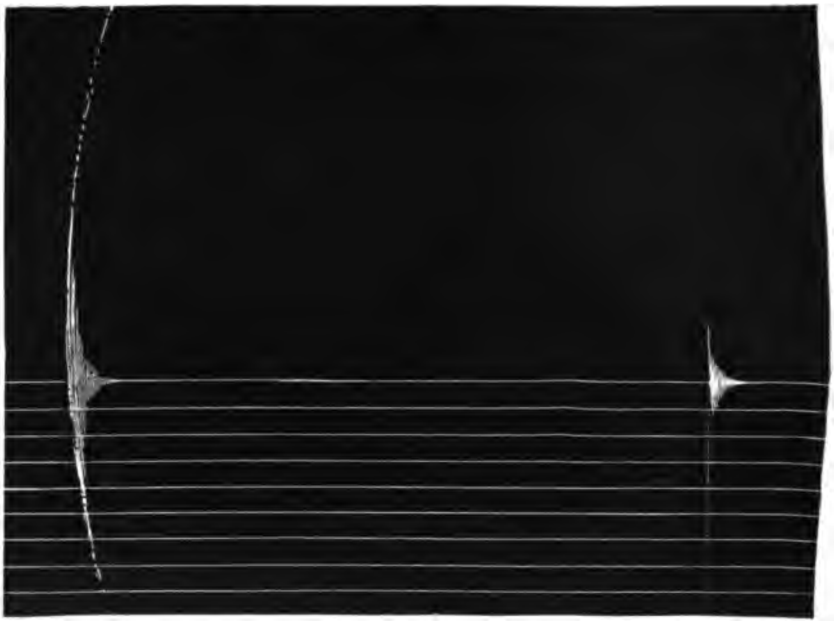

Fig. 2. Records of East-West Components as registered by Omori Seismograph. Berkeley, Cal., October 7, 1915.

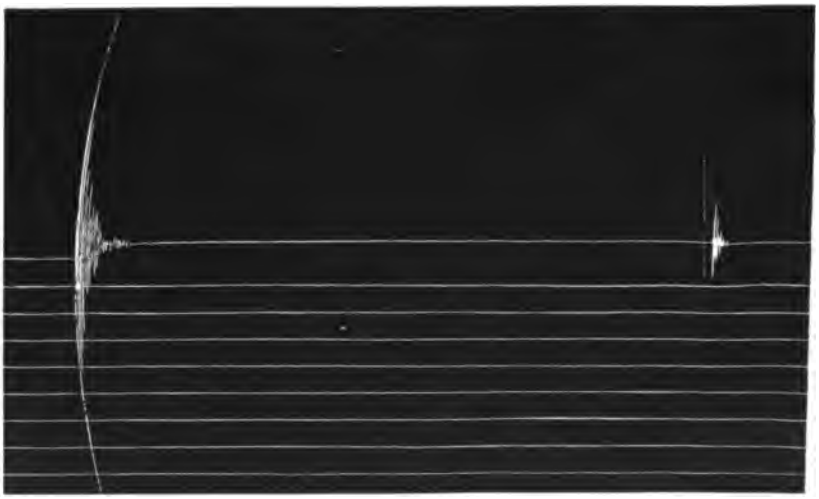

Fig. 3. Records of North-South Components as registered by Omori Seismograph. Berkeley, Cal., October 7, 1915.

ents was practically coincident with the first impulse. In the east-west component the maximum amplitude was 827 microns; in the north-south component the maximum amplitude was 563 microns; in the vertical component the maximum was 170 microns in amplitude, the periods all being about 4/10 of a second. In the vertical component the maximum did not occur at the first impulse, but a second or two later, as shown by the seismogram (figure 1). The movement in this earthquake which was perceptible to human beings lasted seven or eight seconds.

Perceptible movement of the ground was accompanied by a distinct rumbling sound which was distinctly heard by a large proportion of the residents at Berkeley. According to several observers, the shock began with a sound like that of an explosion. One or two reports compared this first sound with that of a boiler explosion.

In Berkeley, the earthquake was estimated to have had an intensity of about VI of the Rossi-Forel scale. At the Berkeley station the tallest Galitzin prism, designed to overturn with an earth acceleration of 200 millimeters per second per second, remained standing after the earthquake. A few cracks were produced in plaster and a small amount of plaster fell in the upper story of Bacon Hall on the University campus. Here and there in Berkeley old cracks in masonry walls appeared to have widened, but in no case were new cracks formed in these walls. In a few instances small loose objects insecurely placed on shelves were thrown down. Hanging lamps were set to swinging. A student rally was in progress in the Greek Theater at this time, and many persons who were seated on the concrete seats there reported that the solid masonry seemed to move beneath them.

In Oakland the intensity was somewhat higher, especially in the region near the base of the hills. In the Piedmont district, which was quite near the origin of the disturbance, a few chimneys were reported to have been thrown down, and some windows were broken. The highest intensity seems, therefore, to have been about VIII of the Rossi-Forel scale. In San Francisco the earthquake was felt quite distinctly, but its character there differed from that in Oakland and Berkeley. Those reporting the earthquake in San Francisco described a slight preliminary tremor before the earthquake proper.

The second earthquake was of very slight intensity, being registered on the north-south Bosch-Omori seismograph as a thickening of the pen trace. It is not apparent on the Omori records (figures 2 and 3) on account of the lack of sensitiveness of that instrument. The writing-pen of the Wiechert Vertical was still in motion from the first earthquake, so that the second slight shock is not apparent on that record. This weak earthquake occurred at 9h 29m 48s.

The seismograms of the third earthquake of this group are shown on the right hand side of figures 1, 2, and 3. This shock occurred at 9h 35m 26s. In Berkeley this earthquake had an intensity of from III to IV of the Rossi-Forel scale. It was accompanied by a rumbling sound much like that heard during the first earthquake. This third disturbance was too strong for satisfactory registration by the Bosch-Omori instruments, but good records were obtained on the Omori tromometer and on the vertical seismograph, as shown in the figures. The seismograms of this earthquake show a slight preliminary motion lasting a little less than half a second. The maximum amplitude in the east-west component was 124 microns; in the north-south component, 105 microns; and in the vertical, 30 microns. The periods were between ½ and ¼ second.

The fourth earthquake was instrumental only, and occurred at 9h 44m 06s.

The fifth shock began at 9h 52m 01s. It was felt by many people in Berkeley, and it is estimated that its intensity was between II and III of the Rossi-Forel scale. The movement of the ground was accompanied by a rumbling sound.

The sixth earthquake was instrumental, and occurred at 9h 55m 55s.

The seventh earthquake was the last one which was felt in Berkeley. It began at 10h 31m 30s. Its intensity was between II and III of the Rossi-Forel scale. It was preceded by a sound which resembled a faint muffled explosion, and was accompanied by a slight rumbling sound.

In addition to the seven earthquakes mentioned above, ten additional after-shocks were recorded at the Berkeley station. They were all of very slight intensity and were not felt by any one. The times of their occurrence are as follows:

7 October	10h	50m	07s	p.m.
	11	54	40	p.m.
	11	56	19	p.m.
8 October	1	47	23	a.m.
	1	59	09	a.m.
	2	57	42	a.m.
	9	16	49	a.m.
	2	44	15	p.m.
	2	44	23	p.m.
11 October	5	29	51	p.m.

An exact determination of the distance of the origin of these earthquakes from the Berkeley station cannot be made, since for such nearby origins the ordinary distance formulae break down. However, an approximate calculation of the distance may be made by assuming the origin to be at, or near the surface of the earth. For such a calculation the velocity of the first preliminary waves may be taken as 6.3 kilometers per second, and that of the main waves as 3.75 kilometers per second. The seismograms of the first strong earthquake showed no trace of preliminary motion, but began abruptly. In such a record there is always the possibility that there are preliminary tremors of short duration, which cannot be separated from the main waves. The third earthquake gave preliminary tremors lasting about ½ second at Berkeley. Some of the stronger after-shocks gave preliminary tremors up to 8/10 second in duration. This variation in preliminary tremors may be taken as indicating that all the shocks did not originate at exactly the same point on the fault. Assuming the origin at the surface and the velocities as above, it will be found that a continuation of preliminary motion (interval $L - P$) for half a second corresponds to an origin distance of 4.6 kilometers or 2.8 miles. An interval $(L - P)$ equal to 8/10 second corresponds to origin distance of 7.3 kilometers or 4.5 miles. While these values are inaccurate, they at least give a very good idea of the magnitude of the epicentral distance, and in that way they are valuable.

There are two active faults in the region of San Francisco Bay which have been known to give rise to earthquakes. These are the San Andreas Rift and the Haywards Rift, the positions of which are shown in the diagram (figure 4). The distance from Berkeley to the nearest point on the San Andreas Rift is approximately 20 miles. An earthquake originating at this distance from Berkeley should show a duration of preliminary motion (interval $L - P$) of from 2½ to 3 seconds. There seems no possibility that a shock with an interval $L - P$ less than a second could have originated elsewhere than on the Haywards Rift near the Berkeley station.

At Santa Clara good records of the first two strong earthquakes were obtained. Through the kindness of Mr. Albert J. Newlin of Santa Clara University the writer was permitted to examine these seismograms. At the Lick Observatory fair horizontal records were obtained of the first earthquake. From the writer's measurements of these seismograms the epicentral distances were found to be 46.8 miles from the Lick Observatory and 35 miles from Santa Clara. Circles were drawn on the diagram (figure 4), one with a radius of 46.8 miles and center at the Lick Observatory, and the other with center at Santa Clara and a radius of 35 miles. These circles intersect near Oakland, as indicated on the diagram. Since it seems unquestionable that the origin of these earthquakes must have been on the Haywards Rift, the most probable position of the origin is the point indicated in the figure, lying east of Oakland, and about midway between the points where the two epicenter circles cut the Haywards Rift.

These shocks are of considerable interest in that they are the first earthquakes of any consequence known to have originated on the northern end of the Haywards Rift since the present seismographic station was installed at Berkeley. Slips which give rise to local shocks of moderate intensity are common on the southern end of this rift, and the strong earthquake of July 1, 1911,[1] had its origin in the same part of this rift.

Like the strong earthquake of July 1, 1911, the first earthquake of October 7, 1915 was not preceded by any fore-shocks. Careful search of the records for the preceding days failed to show any premonitory symptoms of this kind. A possible exception to this state-

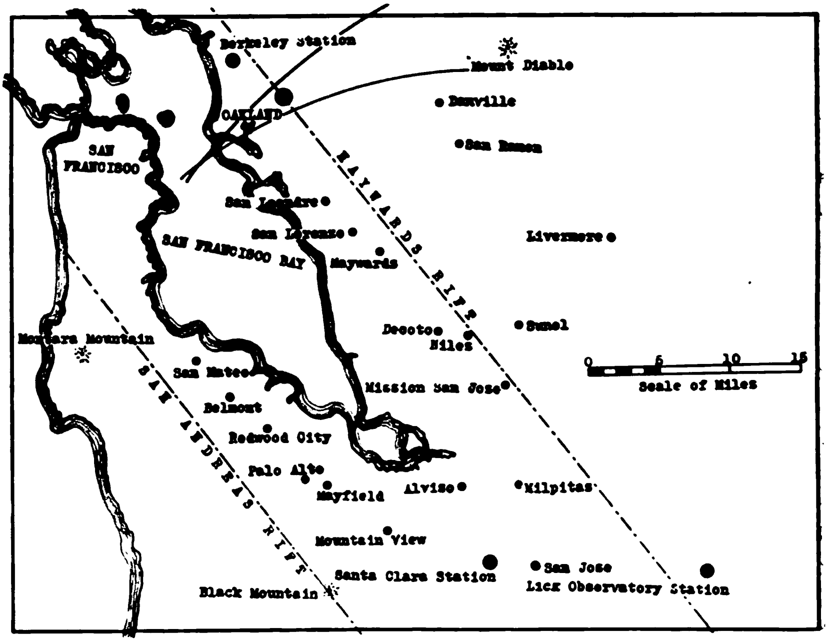

Fig. 4. Epicenter of Earthquake of October 7, 1915.

ment may be found in a very slight earthquake which occurred early in the morning of April 12, 1915. This earthquake was not felt in Berkeley. Its preliminary tremors lasted for about one second. As far as the writer is aware this slight earthquake is the first one of its type ever recorded at the Berkeley station.

University of California,
October 20, 1915.

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[1] H. O. Wood, "On the Region of Origin of the Central Californian Earthquakes of July, August, and September, 1911." *Bulletin of the Seismological Society of America,* **2**, 31 (1912).

SEISMOLOGICAL NOTES

Kingston, Jamaica, September 11, 1915.—Mr. J. F. Brennan of the Public Works Office of Kingston, Jamaica, reports an earthquake shock felt in that city on September 11, 1915, at 6:37 a.m. 75th meridian time. The shock lasted about ten seconds, and there was an extreme horizontal movement of 0.06 of an inch.

Central California, October 1, 1915.—In addition to the reports of this earthquake published in the last number of the BULLETIN, we have the report from the Spring Valley station at Sunol, Cal. The time was reported as 7:27 a.m.; duration two seconds; an accompanying noise similar to a slight explosion. Mr. Ebright, the observer, estimated the earthquake to be III on the Rossi-Forel scale.

Cumberland, England, October 2, 1915.—From *Nature* of October 21st we learn that an earthquake was felt in Cumberland and the surrounding counties on October 2d, at 3:15 a.m. The disturbed area was about forty-five miles long from north to south and about thirty-seven miles wide, and was almost co-extensive with the disturbed area of the Carlyle earthquake of July 9, 1901. Dr. Davison states that this was a twin earthquake, the two foci being separated by about twenty miles.

Utah, October 2 and 3, 1915.—Mr. Frederick J. Pack of the University of Utah has sent seismograms of earthquakes recorded by the seismograph of the University of Utah in Salt Lake City, on October 2d and 3d. Mr. Pack has read the following phases from the seismograms:

October 2, 1915				
P.	23^{h}	39^{m}	00^{s}	G. M. C. T.
S.	23	40	30	
L.	23	41	30	
F.	23	51	00	
October 3				
P.	1	48	20	
S.	1	48	50	
L.	1	49	40	
F.	2	00	40	
B.	6	53	20	dislocated stylus.

Scotland, October 3, 1915.—From *Nature* of October 7th, we learn that a large earthquake was instrumentally recorded at the seismological observatory, Eskdalemuir, Langholm, Scotland, on Oceober 3d, at 7 a.m. G. M. T. The computed position of the epicenter was between Colorado, U. S. A., and the Island of Guadelupe. off the coast of California. [Undoubtedly the Nevada earthquake.]

Central California, October 7, 1915.—The earthquake of October 7, 1915, the epicenter of which was near Oakland, Cal., and of which Mr. Davis has written in the present number of the BULLETIN, was reported from several localities, and a synopsis of these reports is contained in the following tabulation. The locations are arranged in order of distance from the epicenter. Seven of these reports are from the stations of the Spring Valley Water Company.

Location	Observer	Time P.S.T.	Duration	Intensity	Remarks
Oakland,		h m s	s		
Chabot Observatory	C. Burckhalter	9:25 p.m.	3	IV	Rattling
		9:35	1½	III	Rattling
		9:51:30	½–1	I	
San Francisco,					
1800 Broadway	H. Davis	9:25	....	......	Several aftershocks
Lombard Street	Mrs. Kenry	9:30	3	......	
University Mound	W. Lamir	9:30	10	......	Rumbling. Windows, doors, dishes rattled
Lake Honda	N. Persson	9:28	6–7	......	Low rumble
Sausalito	....	9:26	....	......	Light shock
Millbrae					
San Andreas Lake	H. Albrecht	9:31	1½	V	Doors and windows rattled; house swayed
Niles	P. F. Maloney	9:27	½–1	IV	Two shocks separated by one sec.; windows rattled
Newark Slough Station	F. Adams	9:25	1–2	II-III	Two shocks, two-second interval
Lower Crystal Springs	R. Boerner	9:27	2	III	Rumbling noise
Stanford University	....	9:25	...	II-III	

Porto Rico, October 11, 1915.—A slight earthquake was reported from San Juan, Porto Rico, on October 11th, at 3:55 p.m.

Salvador, October 15, 1915.—Newspaper reports from Guatemala City state that over two hundred people lost their lives in Salvador through earthquakes during the seven weeks preceding the middle of October. Many buildings are reported as having been destroyed.

Alaska, October 15, 1915.—A report from Seward, Alaska, states that a shock lasting ten seconds was felt throughout Kenai Peninsula on October 15th, at 7:10 p.m. At Seward it was said to have been accompanied by a mighty roar; but no damage has been reported.

Panama, October 21, 1915.—A slight earthquake was reported on October 21st from Aguadulce, forty miles southwest of Panama. No damage was done, and the shock was not felt in the Canal Zone.

Berkeley, Cal., October 22, 1915.—Mr. E. F. Davis reports an earthquake from Berkeley on October 22d, and writes as follows:—

"A weak local earthquake occurred shortly after 10 p.m. on this date. At the Berkeley station the preliminary tremors had a duration of about one second, indicating that the origin of this earthquake was within a few miles of Berkeley. It seems probable that it originated at or near the focus of the local earthquakes of October 7, 1915.

"Movement of the ground at the Berkeley station began at $10^h\ 18^m\ 33^s$ p.m., and continued until $10^h\ 18^m\ 50^s$ p.m. The movement perceptible to human beings was very short and lasted only about a second, the earthquake being felt by most observers as a single sudden impulse. It is estimated that the intensity in Berkeley was between III and IV of the Rossi-Forel scale.

"The displacement was greatest in the north-south component, the maximum amplitude in that component being sixty microns. In the east-west component the maximum had an amplitude of thirty-five microns. The periods of vibration were short, ranging between half a second and one quarter second."

Asheville, N. C., October 29, 1915.—Two distinct earthquake shocks were felt at Asheville on October 29th at 12:25 a.m. The two shocks came about two minutes apart, and lasted only a few seconds each. They were of sufficient severity to shake the houses and arouse many people from sleep. No damage was reported.

Southern California, November 20, 1915.—An earthquake severe enough to stop clocks occurred in the southwestern part of the United States on November 20th at 4:15 p.m. It was apparently heaviest near Yuma, Arizona, and caused considerable alarm in the Imperial Valley, where much damage was done by an earthquake last June.

Lassen Peak, California.—Two more eruptions of Lassen Peak have been reported, one on October 30th at 7:30 p.m. and the other on October 31st at 11:45 a.m. During the first eruption, which lasted half an hour, the night sky was illuminated by the masses of incandescent material thrown out. During the second eruption, also lasting half an hour, a great white cloud was shot upward 12,000 feet. This was the 119th eruption and was next in size to the largest.

REVIEWS

EARTHQUAKE OF FEBRUARY 10, 1914. By Otto Klotz. Publications of the Dominion Observatory, Ottawa, 3, No. 1.

Dr. Klotz has issued a very complete analysis of the earthquake of February 10, 1914, whose epicenter was located 120 km. northeast of Ottawa, the location making almost an equilateral triangle with Ottawa and Montreal.

At Ottawa the shock was sufficiently severe to rattle windows and slightly move furniture and other objects, and it was not much, if any, more severe at the epicenter. The shock was, however, felt over a very wide area; and this apparent anomaly, of a shock weak at epicenter extending over large areas, was explained by Dr. Klotz, after a complete analysis of the seismograms, which showed the hypocenter to be at a great depth, about 85 km. Thus the distance from hypocenter to epicenter was 85 km., while the distance from hypocenter to Ottawa was only 147 km.

On this point Dr. Klotz states:—

> Obviously the greater the depth of the hearth, the greater relatively will be the extent of country shaken. The quake has got in that case a good grip on the earth, and the differences of intensity on the surface will be less than for more shallow quakes; that is, the gradients of the isoseists will be longer in the former than in the latter case. Furthermore, the nature of the rupture, whether vertical or horizontal, or in an oblique direction to the surface, would be manifested in the dimensions of the disturbed area. The available instrumental records of the quake are so very few that the latter consideration cannot be examined for a definite answer, and we are practically confined to the consideration of our own record.

This publication is concluded with a tabulation of the data received in a large number of reports, and a large map of the country affected, showing all the places where the shock was felt and also many places reporting that the shock was not felt.

S. D. TOWNLEY.

EARTHQUAKES IN JAMAICA. Data concerning earthquakes in Jamaica are carefully gathered and published from time to time, in the government "Weather Reports." Mr. Maxwell Hall, Government Meteorologist, has kindly sent some extracts from these reports. Mr. Hall has carried on some interesting investigations concerning the periodicity of earthquakes and their connection with the rainfall of the island. An adequate review of these studies will not be attempted here, but a brief outline of the main points of the papers may be sufficient to call attention to them, so that those interested may look up the original publications.

The records studied by Mr. Hall cover a period of some forty years, and one interesting result found is that nearly all the earthquakes of the island can be traced to eight distinct epicenters. It is further found that the earthquakes are periodic at all of the epicenters,—these periods ranging from eleven to thirty days. This does not mean, if I understand the tables correctly, that, when the period for any epicenter is say twelve days, an earthquake occurs every twelve days, but that all intervals between earthquakes at that particular epicenter are some multiple of twelve. These periods change, sometimes abruptly, by a fraction of a day. In discussing this periodicity of earthquakes, Mr. Hall suggests a comparison with the action of geysers. He says:—

> In several respects the facts we have deduced respecting earthquakes in Jamaica remind us of the action of geysers: they are regular in their action for a considerable time, and then change their period; and the larger and greater the usual explosive action of a geyser, the longer its period; at least this is the case with the Great Geyser and Strokr in Iceland, according to the graphic descriptions given by Commander Chas. S. Forbes, R. N.

Mr. Hall also makes a comparison between the rainfall in various parts of the island and the frequency of earthquakes, and apparently shows an increased activity during the seasons of lesser rainfall. Years of drought seem also to be followed by years of increased earthquake activity.

> These results, if not as practically useful as might be wished, at least open out wide fields for investigation; they show what may be done without instrumental means; and clearly there is an interesting future for the study of this particular class of earthquakes.

S. D. TOWNLEY.

VELOCITA DI PROPAGAZIONE DEL TERREMOTO MARSICANO DEL 13 GENNAIO, 1915. Nota di G. Agamennone. Rendiconti della R. Accademia dei Lincei. Classe di scienze fisiche, matematiche, e naturali. **24**, serie 5a, 1° sem., fasc. 5°. Seduta del 7 marzo 1915.

This note follows the article already reviewed in this BULLETIN.[1] Having corrected some of the data used in the previous article and utilizing new data, the author concludes that the average surface velocity of the seismic waves was about 7530 meters per second.

He finds a varying velocity, increasing between 155 and 391 kilometers from the epicenter, uniform between 391 and 620 kilometers, and decreasing to the initial velocity between 927 and 1420 kilometers from the epicenter.

For a longer distance, as to Cambridge and Ottawa, his data give him a greater velocity of 11,100 meters per second.

C. G. ALLEN.

LA FORTISSIMA SCOSSA A MESSINA DEL 22 DICEMBRE, 1912. By G. Agamennone. Estratto dalla "Rivista di Astronomia e Scienze Affini," Anno VII, Aprile, 1913.

The article contains notes on the earthquake at Messina of December 22, 1912. Its intensity was VII of the Mercalli scale. Although rather severe it caused no damage, owing to the character of the new buildings at Messina. The epicenter was in the northeast of Sicily, in the neighborhood of Messina. The shock was felt over a distance of some 200 kilometers in a direction N-NE and S-SW from Messina. It was registered by instruments in various parts of Italy, Austria, and Germany.

The earthquake was not announced by any preliminary shock, but was followed by six minor shocks the same day, after which followed a period of comparative calm.

C. G. ALLEN.

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[1] *Bulletin Seismological Society of America*, **5**, 112.

SEISMOLOGICAL REPORTS RECEIVED

AMERICA

Denver, Colorado, Jesuit Seismological Service.—Reports nos. 9 and 10, from September 1, 1915 to October 31, 1915.

Harvard University, Cambridge, Mass.—Record of the Seismographic Station, nos. 11-18 inclusive, from June 22, 1915 to November 30, 1915.

University of Santa Clara, Cal., Jesuit Seismological Service.—Reports nos. 155 to 160 inclusive, from September 7, 1915 to October 8, 1915.

Ottawa, Canada, Earthquake Station, Dominion Astronomical Observatory.—Reports nos. 15 to 20, from September 1, 1915 to November 30, 1915.

Washington, D. C.—Seismological Bulletin of Georgetown University, Department of Geology, Reports nos. 7 and 8, from October 1, 1915 to December 1, 1915, including 7 bis.

ASIA

Zi-Ka-Wei, China.—Bulletin Sismique, nos. 8 to 13, from May 27, 1915 to September 3, 1915, including 2-3-4 bis, 5-6-7 bis, 8-9 bis, 10-11 bis.

EUROPE

Barcelona, Spain, Estacion Sismica do la Real Academia de Ciencias y Artes.—Boletin Sismico, nos. 16 to 18, from July 1, 1915 to September 30, 1915, including 17A.

Granada, Spain, Estacion Sismologica de Cartuja.—Boletin Mensual, nos. 6 and 7, June and July, 1915.

Coimbra, Portugal, Observatorio Meteorologica, Magnetico e Sismico da Universidade.—Boletim Sismico, nos. 4B to 8A, from June 1, 1915 to September 30, 1915.

PHILIPPINE ISLANDS

Manila, P. I.—Seismological Bulletins of the Observatory, nos. 11 to 23, from May 1, 1915 to August 31, 1915.

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ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

VI. **Fairly strong shock**: general awakening of those asleep, general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. **Very strong shock**: fall of chimneys, cracks in walls of buildings.

IX. **Extremely strong shock**: partial or total destruction of some buildings.

X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

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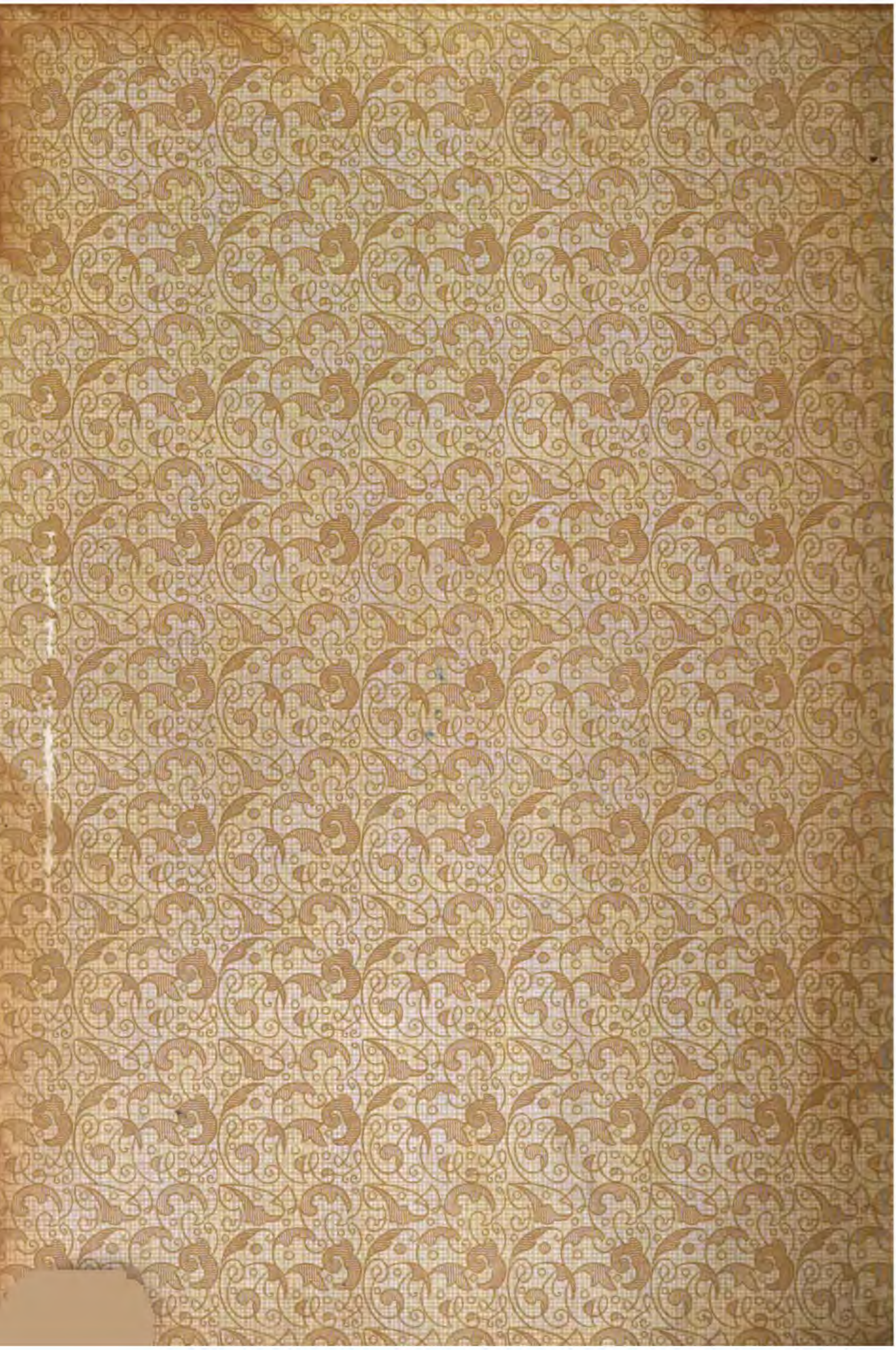

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